

research based education 2016

Volume One

6102 966

International peer reviewed conference

aae 2016

curiosity

production

risk

participation

In partnership with



association of
architectural
educators



The Architectural Review

SCOTT
BROWNRIGG

bartlett.ucl.ac.uk/architecture
aae2016.org
#aae2016

aae2016 International Peer-reviewed Conference on 'Research Based Education' hosted by The Bartlett School of Architecture, University College London, UCL, UK, 7-9 April 2016

Volume One

The papers in this book include the proceedings of aae2016 conference held in London in April 2016. The papers were blind-reviewed and copy-edited but they only reflect the authors' opinions. Inclusion in this publication does not necessarily constitute endorsement by the editors, the association of architectural educators (aae) or The Bartlett School of Architecture, UCL.

No material, whether written, photographic or electronic, may be reproduced without the permission of the authors, designers and The Bartlett School of Architecture.

© 2016 The Bartlett School of Architecture, UCL and the authors

Conference Steering Group:

Prof. Alan Penn
Prof. Bob Sheil
Prof. Iain Borden
Dr Penelope Haralambidou
Frosso Pimenides
Patrick Weber
Oliver Wilton

Publisher:

The Bartlett School of Architecture, UCL

Conference Website & Administrator:

Marilena Skavara

Twitter: @BartlettArchUCL
Facebook: BartlettArchitectureUCL
Instagram: bartlettarchucl
Vimeo: vimeo.com/bartlettarchucl

Conference Coordinator & Editor:

Patrick Weber

Copy Editing:

Benjamin Clark
Rebecca Spaven

The Bartlett School of Architecture
University College London
140 Hampstead Road
London NW1 2BX

Editorial Production:

Robert Newcombe

+44 (0)20 3108 9646
architecture@ucl.ac.uk

ISBN 978-0-9929485-9-7

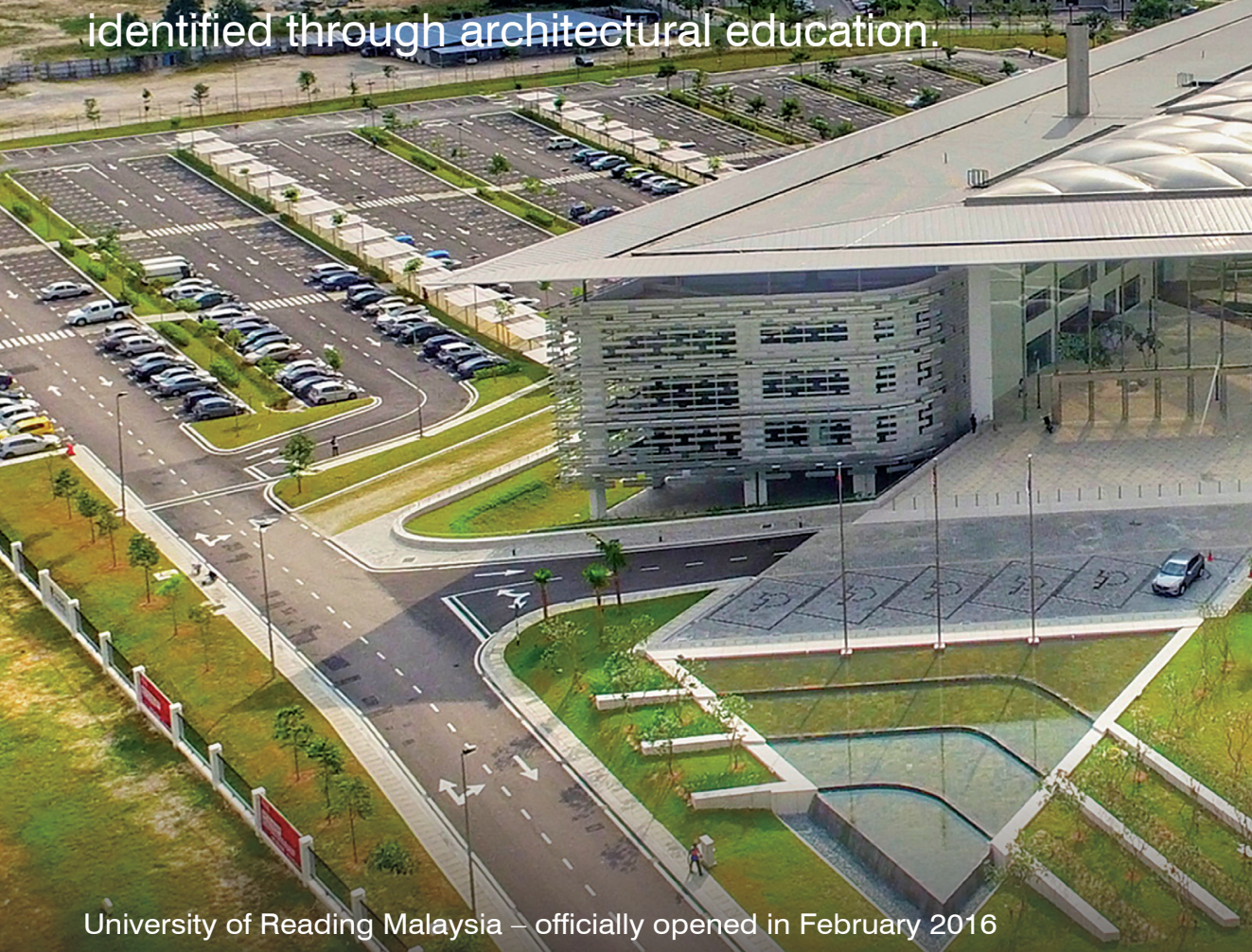
aae2016

Hosted by *The Bartlett School of Architecture, UCL* in collaboration with the association of architectural educators (aae), **aae2016** is an International Peer Reviewed Conference on 'Research-Based Education' which runs from 7 to 9 April 2016.

The aae2016 is part of Bartlett 175, an exciting series of events celebrating the 175 years of architectural education at UCL.

At a pivotal time for architectural education, this conference will bring together global innovators in education, research and practice to interrogate the diverse natures and interrelationships between these realms as they relate to architecture, and to discuss how and why they may evolve over the coming century. The conference will include sessions on the themes of **Curiosity, Risk, Participation** and **Production**.

Scott Brownrigg is committed to supporting the next generation of architects and to the talent identified through architectural education.



University of Reading Malaysia – officially opened in February 2016



SCOTT
BROWNRIGG



scottbrownrigg.com

Thanks to:

aae2016 main title supporter

**SCOTT⁺
BROWNRIGG**

Supported by



Media Partner

The Architectural Review



aae
association of
architectural
educators

Study at The Bartlett

Undergraduate / Architecture / Architectural and Interdisciplinary Studies / * Engineering and Architectural Design

Postgraduate Taught / Architecture / Architectural History / Architectural Design / Urban Design / Spatial Design: Architecture + Cities / Architectural Computation / Architecture and Historic Urban Environments / Architecture and Digital Theory / * Situated Practice / * Design for Performance and Interaction / * Design for Manufacture / ** Landscape Futures

Postgraduate Research / Architectural Design / Architectural History and Theory / Architecture and Computation

Short Courses / Summer School / Summer Studio / Summer Special / Summer Skill-ups / Sir Peter Cook Masterclass / Pre-Masters Certificate in Architecture

bit.ly/b-study



* Launching 2017
** In development

Bartlett 175

Celebrating 175 years of Architectural Education at UCL

January – March & September – December

Bartlett International Lecture Series

Our major public lecture series held on Wednesday nights with stellar names in architecture, design, art and architectural theory.

January

The Donaldson Lecture

The inaugural lecture in a new series celebrating architecture and education, by artist Grayson Perry CBE.

February

Think Space

A forum for cross-disciplinary discussion and debate curated by Jeremy Melvin. The first of these free evening events focuses on the intersections between art, architecture and neuroscience.

February

PhD Conference

An annual conference, exhibition and publication showcasing cutting-edge work in architectural design and architectural history and theory research.

March

Open Crits

An annual series of public all-day crits of our students' work, with invited critics from architecture, design and the media.

April

Association of Architectural Educators Conference

A major international conference on the theme of 'Research-Based Education'.

May

R&V Dinner

An alumni event hosted by the School attracting over 100 Bartlett School of Architecture alumni. Chaired by Paul Monaghan, Director, Allford Hall Monaghan Morris.

June – July

The Bartlett Summer Show

Over 500 students exhibit drawings, models, films and more in this major event attracting over 10,000 visitors.

August

Brought to Light

An online exhibition of compelling in-progress photographs by Paul Smoothy of The Bartlett's home as it is refurbished. The project uses black and white analogue photography to trace the transformation of 22 Gordon Street.

September

B-Pro Show

The annual exhibition of our ground-breaking post-professional advanced Architectural Design and Urban Design programmes, which is fast becoming a fixture on the architectural scene.

October

The Big Draw

An architecture-themed free family day as part of a major national initiative to get children drawing, the Campaign for Drawing's 'Big Draw'.

November

Drawing Futures Conference and Book Launch

A new peer-reviewed conference examining the critical role of drawing in relation to technology, contemporary architectural practice and beyond.

November

FBASA at WAF and Venice

Friends of The Bartlett School of Architecture, a new alumni and friends organisation, hosts social events at the World Architecture Festival in Berlin and the Venice Biennale.

December

80 at 80

An exhibition of drawings by The Bartlett's Professor Sir Peter Cook RA, on the occasion of his 80th birthday.

December

22 Gordon Street Opening

The opening celebration of our recently renovated home at 22 Gordon Street, formerly Wates House.



@BartlettArchUCL
#Bartlett175
bit.ly/bartlett175



Conferences + Publications

DRAWING FUTURES

10-11 November 2016

The Bartlett School of Architecture

Speculations in contemporary
drawing for art and architecture

drawingfutures.com

[#drawingfutures](https://twitter.com/drawingfutures)

FABRICATE

6-8 April 2017

University of Stuttgart

Pioneering design and making
in architecture, construction,
engineering, manufacturing,
materials technology and
computation

fabricate2017.org

[#fabricate17](https://twitter.com/fabricate17)



Contents

Volume 1

Introductions

| | |
|---|----|
| Alan Penn , Dean, The Bartlett, UCL's Faculty of the Built Environment | 18 |
| Professor Bob Sheil , Director, The Bartlett School of Architecture | 20 |
| The aae Victoria Farrow | 22 |

curiosity

Keynote

| | |
|---|----|
| <i>Curiosity</i> Izaskun Chinchilla | 24 |
|---|----|

Papers

| | |
|---|----|
| <i>Pedagogic poetics</i> | 26 |
| Marjan Colletti , The Bartlett School of Architecture, UCL, UK and University of Innsbruck, Austria | |
| <i>Space & play time - the value of the speculative act in architectural design (education)</i> | 34 |
| David Short , University of Nottingham, UK | |
| <i>Fieldwork</i> | 44 |
| Simon Herron, Susanne Isa , University of Greenwich, UK | |
| <i>A series of 'happy accidents'</i> | 50 |
| Victoria Farrow , Birmingham City University, UK Stephen Garrison , Marywood University, USA | |
| <i>Learning environments in design studio culture: exploring the student experience</i> | 58 |
| Julian Williams , University of Westminster, UK | |
| <i>The studio as site: Exploring the positionality of the designer in the creative process</i> | 66 |
| Matt Ozga-Lawn, James A. Craig , Newcastle University, UK | |
| <i>Design Research in Architecture: The Path towards Research-Based Education</i> | 80 |
| Professor Murray Fraser , The Bartlett School of Architecture, UCL, UK | |

| | |
|--|-----|
| <i>Collective agency: the architectural collective as an emerging model for education and practice in Brazil and the UK</i> | 86 |
| Jane Hall , Royal College of Art, UK | |
| <i>Design prototype</i> | 96 |
| Claudia Pasquero , Bartlett School of Architecture, UCL Emmanouil Zaroukas , University of East London, UK | |
| <i>Drawing from curiosity: The role of reflective drawing in architectural design, research and learning</i> | 109 |
| Dr. Miguel Jaime , Department of Architectural Engineering, Alhosn University, UAE and Dr. Eugenia Lopez Reus , Department of Architecture and Design, Abu Dhabi University, UAE | |

production

Keynote

| | |
|---------------------|-----|
| <i>Production</i> | 120 |
| Achim Menges | |

Papers

| | |
|--|-----|
| <i>The robot and the swallow: sustainable practice in a digital world</i> | 122 |
| Guan Lee & Eleanor Morgan , The Bartlett School of Architecture, UCL, UK | |
| <i>RAF A framework for symbiotic agencies in robotic – aided fabrication</i> | 130 |
| Alicia Nahmad Vazquez & Dr. Wassim Jabi , Welsh School of Architecture, Cardiff University, UK | |
| <i>Design-research by making: an educational hands-on approach to design-research through manual/robotic processes</i> | 150 |
| Ioanna Symeonidou, Renate Weissenböck , Institute of Architecture and Media, Graz University of Technology, Austria | |
| <i>Design methods: deep agencies for spatial production</i> | 162 |
| Perry Kulper , Taubman College of Architecture and Urban Planning, University of Michigan, Michigan, USA | |
| <i>Hybrid design workflows of digital crafting and material computation</i> | 174 |
| Soomeen Hahm, Igor Pantic , The Bartlett School of Architecture, UCL, UK | |

| | |
|--|-----|
| <i>Research-based teaching as a search for novelty in architectural education</i> | 184 |
| Derya Yorgancioğlu , Istanbul Kemerburgaz University Dept. of Architecture, Asst. Prof. Dr., Istanbul, Turkey | |
| <i>Between design and digital: bridging the gaps in architectural education</i> | 192 |
| Shelby Doyle, Nick Senske , Iowa State University, USA | |
| <i>Material / tooling / prototyping: the production of full-scale models in architectural education</i> | 210 |
| Evan Greenberg , Architectural Association, School of Architecture, UK | |
| <i>Crafting skins: spatial and structural properties of laminated surfaces</i> | 218 |
| Michael Budig , Singapore University of Technology and Design, Singapore and Dishita Turakhia , Massachusetts Institute of Technology, USA | |
| <i>From continuous to discrete fabrication</i> | 231 |
| Gilles Retsin, Manuel Jimenez Garcia, Vicente Soler , The Bartlett School of Architecture, UCL, UK | |

Volume 2

Workshops

| | |
|---|-----|
| <i>Framing your live project within a design research methodology</i> | 262 |
| Jane Anderson , Oxford Brookes University, UK Ruth Morrow , Queen's University Belfast, UK | |
| <i>How computational agent-based models trigger creative insights into architectural and urban design education</i> | 266 |
| Kinda Al Sayed , Bartlett School of Architecture, UCL, UK | |

risk

Keynote

| | |
|-------------------------|-----|
| <i>A risky business</i> | 282 |
| Lesley Lokko | |

Papers

| | |
|--|-----|
| <i>Code-breaking: curiosity through the critical examination of 'cultural software' in architectural education</i> | 284 |
| Luke Pearson , The Bartlett School of Architecture, UCL, UK | |

| | |
|---|-----|
| <i>Palimpsestuous design: playing with architecture</i> | 297 |
| Paula Craft-Pegg , University of Portsmouth, UK | |
| <i>The freedom of the sketch and the tyranny of the digital image</i> | 309 |
| Douglas Gittens, Amanda Hufford , Nottingham Trent University, UK | |
| <i>About the process of design</i> | 318 |
| Toby Lewis , University of Bath, UK | |
| <i>Education for uncertainty</i> | 326 |
| Lorraine Farrelly & Flora Samuel , School of Architecture, University of Reading, UK | |
| <i>Negative capability in the design studio</i> | 338 |
| Sandy Litchfield , University of Massachusetts Amherst, USA | |
| <i>Goodbye Mister Bond: 007's critical advocacy for feminism & modernism</i> | 348 |
| Dr. Harriet Harriss , Royal College of Art, London, UK | |
| <i>Tactics developed in times of economic crisis applied in design studios</i> | 358 |
| Kirill Jedenov , University of Western Australia Filipe Afonso , Chinese University of Hong Kong | |
| <i>Liquid states and concrete uncertainties</i> | 372 |
| Olivier Ottevaere , The University of Hong Kong/Double[o]studio, Hong Kong | |
| <i>A certain degree of uncertainty: embracing risk in the thesis project via the 'creative survey'</i> | 382 |
| Carolyn Butterworth , The University of Sheffield, UK | |

participation

Keynote

| | |
|---|-----|
| <i>Participation and professional education in the 21st century</i> | 394 |
| Etienne Wenger | |

Papers

| | |
|--|-----|
| <i>Take the red pill: a journey into the rabbit hole of teaching informed research</i> | 396 |
| Dr Charlie Smith , Liverpool John Moores University, UK | |

| | |
|---|-----|
| <i>#Mcgillarchitecture: design education in the age of instagram</i> | 407 |
| Annmarie Adams , McGill University, Canada Basem Eid Mohamed , Abu Dhabi University, UAE | |
| <i>Towards a connected curriculum in architectural education: research-based education in practice</i> | 416 |
| Brent Carnell , Centre for Advanced Learning and Teaching, UCL, UK | |
| <i>Architecture and engineering: interdisciplinary education</i> | 427 |
| Dr. Rachel Cruise , School of Architecture, University of Sheffield, UK | |
| <i>A combined approach to engineering and architectural education</i> | 439 |
| Alastair McDonald , Faculty of Engineering and the Environment, University of Southampton, UK | |
| <i>Nurturing the citizen designer: re-defining participatory frameworks for professional re-alignments</i> | 452 |
| Arunava Dasgupta , School of Planning and Architecture, New Delhi, India | |
| <i>Human computer interaction systems and educational strategies to support design participation</i> | 468 |
| Robert Aish , The Bartlett School of Architecture, UCL, UK | |
| <i>Digital tools beyond aesthetics: mass creativity and the enablement of emergence</i> | 481 |
| Dimitrie A. Stefanescu , The Bartlett School of Architecture, UCL, UK | |
| <i>Insights from ntnu live studio</i> | 490 |
| Elena Archipovaite , Hans Skotte , Steffen Wellinger , Faculty of Architecture and Fine Arts, Norwegian University of Science and Technology, NTNU | |
| <i>Living architecture: currencies between architectural pedagogy and time-based media performance</i> | 503 |
| Ava Fatah Gen Schiek , Bartlett School of Architecture, UCL, UK | |

Introduction

Alan Penn

Dean, The Bartlett, UCL's Faculty of the Built Environment

It is especially apt that UCL, 190 years after its foundation, is hosting the association of architectural educators conference. UCL was founded on the heels of the enlightenment with the radical mission to improve the lot of all through education and scholarship. The appointment in 1841 of Thomas Leverton Donaldson, a founder just two years previously of the RIBA, to the first Chair of Architecture in a British University was one in a series of UCL 'firsts': the first Chairs of Chemistry, Engineering and Chinese; the first to admit those of the Jewish faith; the first to admit women on the same terms as men. All of these flew in the face of the medieval and religious scholastic foundations of the two English universities.

Few at that time could have foreseen just how radical the study of architecture would become, and I would argue that today this understanding is still not mainstream. Here I only have space to say first why I think architecture is radical, and so why its education is also, and then to give some examples of things we are doing at The Bartlett to extend that tradition. I am confident that the conference will give additional opportunities to explore these issues.

The enlightenment marked a change in the way that people conceived of many things, not only the relation between the physical and material world and that of theories and ideas, but also the relations between people, politics and the legitimacy of government. This kind of change is a remarkable characteristic of human culture and one that was perhaps first recognised in the 20th century with the psychological turn in social science through the concept of inter-subjectivity. Briefly, this refers to those aspects of our subjective understanding or the world that must be shared between people as the assumptions that allow common social action to take place. Thus Francis Bacon's empiricism, Descartes' logic, Spinoza's antiteleology and Locke's concerns with political legitimacy all came together to create a new inter-subjective set of norms and assumptions on which, first, Western science, and next, the modern state were built.

Roll forward to today. It is now beginning to be understood that the built environment forms an 'inter-objective' realm, complementary to the inter-subjectivity of ideas, creating as it does a layer of objective constraint on human action, association and transaction. There

are some who argue that it was the invention of proto-urban form that led to the first flowering of civilisation in the ancient near east, the invention of settled agriculture, writing, money and of state formation. If this is so, then it is the role of the radical architect and planner as much as the philosopher to invent new possibilities for social formation.

How then does this work? Every act of construction – building walls and enclosures, streets and thresholds – creates a potential for human occupation, movement and interaction, and in doing so reduces other potentials. Construction does not uniquely specify social interactions, as other factors are also involved: patterns of social function and land use, the regular daily cycles of activity, social rules on space use or ownership and so forth; but spatial design plays a powerful role in structuring the field of possibility for social relations. There is no doubt about the complexity of the interactions of all these dimensions, as well as of the feedback from the social that affects the configuration of the built environment. There is equally little doubt about the feedback from the spatial onto the social and economic. The whole is entailed into a complex and emergent system in which is essentially ‘lived and behaved’ for the most part subconsciously.

The mainly subconscious enactment in the spatial world out of which social structures emerge is similar to the subconsciousness of our acceptance of inter-subjective assumptions and norms in the realm of thought. It is precisely the fact that architecture and the built environment is ‘lived’ subconsciously rather than ‘thought about’ consciously that creates the specific challenge of architectural education. The architect must learn to intuit the emergent outcomes of new and never before constructed environments on patterns of social behavior and interaction, and to do so both through use of their own subconscious intuition, but also to be consciously aware and reflective on these. The architect as a reflective practitioner, like a tennis player, must train to act without thinking, but at the same time to think completely strategically.

In order to challenge existing assumptions we are exploring new models of architectural education. First, the assumption that the architect’s prime responsibility is to their client. We are working to develop an ethical code for the built environment professions that places priority instead on responsibility to society at large and future generations. This will be fundamental to the delivery of a more sustainable world. Second, we are working to challenge disciplinary divides between areas of professional knowledge. For example we are developing a new undergraduate program MEng in Engineering for Architectural Design, linking between The Bartlett’s School of Architecture, its Institute of Environmental Design and Engineering and The Department of Civil, Environmental and Geomatic Engineering. Third, the assumption of individual authorship in creative practice. We are learning from educational methods in time-based and performing arts to investigate whether new models of collaborative creativity can be developed for architectural design. We are at an early stage in plans for all three areas of work.

Introduction

Professor Bob Sheil

Director, The Bartlett School of Architecture

The form, purpose, and direction of architectural education generates continual debate, and in our time probably more so than in any period before. Fundamentally this stems from its creative core, an energy that is constantly buzzing, seeking renewal, opening doors, and responding to change. In addition, its dual role as a structure to prepare students for practice, and a terrain that offers up the subject at large, is in itself a chemical exchange. Both sides of this challenge are on a spectrum that extends from the sharp perimeters of each domain to the agitated blur of spaces they both occupy. These perpetual reactions are what make architectural education one of the most exciting, demanding, influential and significant enquiries of human learning and development.

In the UK, the undergraduate programme itself is one of the most powerful transformative agencies in higher education as a whole, generating graduates of extraordinary diversity, ability, flexibility and insight. The bridge they cross into their first exposure to industry and the profession is not always smooth, but it is without doubt a pivotal experience of transition from learning to application that industry profits from in a myriad of ways. The year – or two years – out, and subsequent postgraduate education, followed by a further stint in professional learning and development, add up to a long and challenging path that is increasingly difficult to traverse.

The dominant issues fuelling debate today surround longevity, cost, and accessibility. Skill is another key issue. Institutions of governance, regulation, policy and education are engaged in fraught and complex calculation on how best to tackle the many conundrums that lie ahead. Meanwhile, the entire industry of architectural education is predominantly underpinned by two core communities, teachers and researchers, neither of whom always get a look-in on the big decisions, even though the vast majority operate across the spectrum of practice, education and research every day.

We are extremely pleased to be hosting the association of architectural educators conference at such a time. aae represents the individuals and experiences that occupy the coalface of our activity. Year in, year out, they explore, develop, imagine, and read the circumstances in which we operate and respond with insightful approaches. They

write the briefs that operate as vessels of learning, provocation, exploration and delivery. They spin an inordinate number of plates with great ingenuity, on top of which they act as pastoral carers to their closest audience. Behind the scenes they develop their own positions as either researchers or practitioners, or in many cases both. What this demonstrates clearly is how the environment of education is a profound generator that defines and shapes architectural knowledge and expertise, complementing industry and practice in ways that are vital and unique.

It is timely, therefore, that aae2016 is devoted to recognising this status under the theme of ‘research-based education’, a defining characteristic that applies to architecture in ways that need far greater recognition than it presently enjoys. Research-based education in architecture is extraordinarily rich and diverse, as well as innovative. It is a field of learning where research and education started at the same time as the profession was formed. At UCL this year, we are celebrating 175 years since the appointment of our first Professor in Architecture in 1841, Thomas Leverton Donaldson, a founder of the RIBA when it was established in 1836. The year’s events range from academic conferences to a special publication produced with the Architectural Review, to exhibitions and alumni activities. We are grateful to supporters within UCL and across industry, particularly the aae2016 Main Title sponsors Scott Brownrigg, for enabling us to host the event.

In his inaugural address, Donaldson declared:

“We are all, in fact, in a state of transition ... We are wandering in a labyrinth of experiments ... thus creating a new and peculiar style. This movement has placed the schools of all countries in a state of great uncertainty; as yet we have no fine leading principle as a guiding star”.

On this note of confident recognition that architectural education is inextricably bound to the notion of research, we welcome you to this conference, its proceedings and its debate.

Introduction

The aae

Victoria Farrow

The aae (association of architectural educators) was founded in September 2011. A collaboration of academics from various institutions in the UK we established the following aims through which we direct our activities. These aims are instrumental to our agenda within architectural education.

THE ASSOCIATION OF ARCHITECTURAL EDUCATORS (AAE) AIMS:

1. To develop, support and represent communities of practice and learning in architectural education in the U.K. and Ireland.
2. To foster inclusive dialogues between the aae community, students and employers, and educational and professional bodies.
3. To encourage research and scholarship of teaching and learning in architectural education through critical and reflective discourse.
4. To promote the value, richness, quality, and diversity inherent in architectural education.

The aae benefits from a group of enthusiastic members with representation from schools based in the north, south, east and west, we are fortunate to have support and input from a rich community of architectural educators. This helps us to achieve our three key outputs, including hosting an annual aae international conference, the production of the aae journal Charrette and to support the committee working to develop the organisation itself.

THE AAE STEERING COMMITTEE'S MEMBERS (2015-16):

- Chair & Co-Treasurer: Hannah Vowles, Birmingham City University
- Vice Chair: Dan Jary, University of Sheffield
- Secretary & Co-Treasurer: Victoria Farrow, Birmingham City University
- Web coordinator: Julian Williams, University of Westminster
- Charrette editor: Professor Ruth Morrow, Queen's University Belfast
- Charrette assistant editor (formerly series editor): James Benedict Brown, De Montfort University

TO DATE THE AAE HAS HOSTED TWO CONFERENCES:

In April 2013 we formally launched the association of architectural educators together with Charrette at Nottingham Trent University. This event was followed by our second conference at the University of Sheffield in September 2014. Both were very successful and have helped us to sustain material for the journal but also have enabled us to remain engaged and contributing to the architectural community that support us. We are thrilled that The Bartlett has been able to host our third conference in line with their 175th anniversary and very much look forward to the event.

ADDITIONAL ACTIVITIES INCLUDE:

aae and Vectorworks scholarship programme

This programme provided free software licenses to staff, students and schools in-house along with a range of other benefits such as a support page, workshops, and access to a range of resources online for staff and students.

aae BIM camps

The BIM camps look to support architectural educators and their students through the provision of knowledge and guidance in BIM. The first aae BIM camp was hosted at Birmingham City University in January 2016 and we are now looking to provide further BIM camps to other member schools.

National Conference on the Beginning Design Student

Our links with NCBDS together with sponsors including Scott Brownrigg and Vectorworks allow us to tap further into the international communities of architectural educators and also further afield. As a growing organisation we welcome your support.

Thank you for being a part of our development.

Keynote

Izaskun Chinchilla

Curiosity

The goal that has guided both the research and drafting of this intervention has been to be truly useful to architects and designers who, by self conviction or through third parties, want to devise and implement a more ecological or more social development of architecture or design products. My intervention will propose to these professionals a new design manifesto: a deeper application of ecological and social principles to architecture would change everything; it wouldn't be a partial change, it would mean a revolution. Under this new declaration, a closer link between ecology, sociology and innovation is set; making ecological architecture and design necessary to impact change, progress, and achieve higher levels of organization. To achieve greater success with fewer resources signifies, therefore, to innovate.

To describe how a profession may face a revolution, this intervention has drawn on the book published in 1962, and extended in 1969, 'The Structure of Scientific Revolutions' by Thomas Kuhn. This book has provided the instrumental definition of key terms such as architecture, revolution and normal science, which have influenced the structure of chapters and helped to identify the details of architectural work and its socialization within the professional guild. The title of this intervention aims to be an explicit recognition of the importance of terms as curiosity, discovery and invention in Kuhn's book.

curiosi
production
risk
participation

‘A deeper application of ecological and social principles to architecture would change everything; it wouldn’t be a partial change, it would mean a revolution’

In general, the intervention is aimed at architects whose training in ecology and innovation has not played an essential role. Therefore, part of this acknowledgment and the description of design practices are common. Descriptions of how architects design without pursuing ecological and innovative maxims will be abundant. These descriptions reveal, through analysis and diagnosis, design principles which play an important role in structuring the professional practice, and which, however, are applied informally; without specific hypotheses or methodological justification. What role do masterpieces or visual references in teaching and design practices play? How do architects use terms like elegance, consistency and sincerity when they speak about the virtues of their projects? What challenges, within a project, are formulated as problems with solutions? Which methodological aspects are never mentioned? That these informal procedures are precisely those which more decisively contribute to limit the penetration and impact of the ecological paradigm is one of the hypotheses offered to the audience.

In addition to this individual utility as a vehicle for the transformation of design methods, the intervention aims to contribute to a collective and institutional debate on the present challenges of pedagogy, evaluation and implementation of the architecture project. The collective utility that guides the drafting of the intervention is to transform into new professional opportunities the challenges arising from the ecological crisis and to encourage architects, and the institutions they lead, benefiting from the resources and incentives linked to innovation. To reach this dual purpose, individual and collective, I will try to describe a structure, which may make institutions more capable of promoting ecological practices and innovative design. What would be the political implications of a collective change to design methodologies? How do institutions contribute to the establishment of a collective speculation of what the ecological architecture and city are? What role do we bestow upon images? And upon social agendas?

Overall, the methodological reflection of the proposal is articulated in the format of a reflection to design new pedagogic plans. That training plan intends to be useful, as already mentioned, to recycle professionals trained with different perspectives. But an equally important objective is to contribute to the definition of basic principles for a new undergraduate and social role of the architect and designer profession.

ty

Pedagogic poetics

Marjan Colletti

The Bartlett School of Architecture, UCL, UK and University of
Innsbruck, Austria

In this paper I will argue that top-down tactics of delivering knowledge in architectural education should be considered out-dated, ineffective and unproductive, and that research-based education must adopt a more bottom-up, and poetic, approach towards research-led education. This supposition is based on the grounds that contemporary architectural industry is unthinkable without computational aid, and that today's teens and pre-teens are the first officially digitally-educated generation. Practice is already reacting to the shifting paradigms of a digitalized world, and school education already presumes literacy and spontaneity with information and communications technologies. Consequently, it seems unavoidable that higher education institutions should be prepared to accommodate these very students who are used to interact with digital technologies and computer-based learning, and to allow them to thrive thanks to new tools and technologies and capitalise on the emergence of collaborative intelligence, network learning and distributed problem-solving systems.

TOP-DOWN PEDAGOGICS

A priest on a pulpit; a judge on a raised bench; a tennis umpire in a high chair – these are only a few examples of how to literally deliver knowledge top-down. Not surprisingly, this spatial construct pretends to be capable of teaching what is right and what is wrong. It is a constitutive part of architectural education to consider and to discuss true and false ways of doing things. For example, in terms of building construction, how to do suitable details in order to insulate buildings properly, erect decent structures to make it robust and sound, and find virtuous ways of complying with norms and regulations. But also how to avoid incorrect sizing of rooms, erroneous financial planning and inappropriate material choices and so on. However, when it comes to architectural design, the issue of good and bad, right and wrong, true and false becomes extremely complicated. A huge amount of decision-making is not quantifiable, not specifiable, and arguably not teachable.

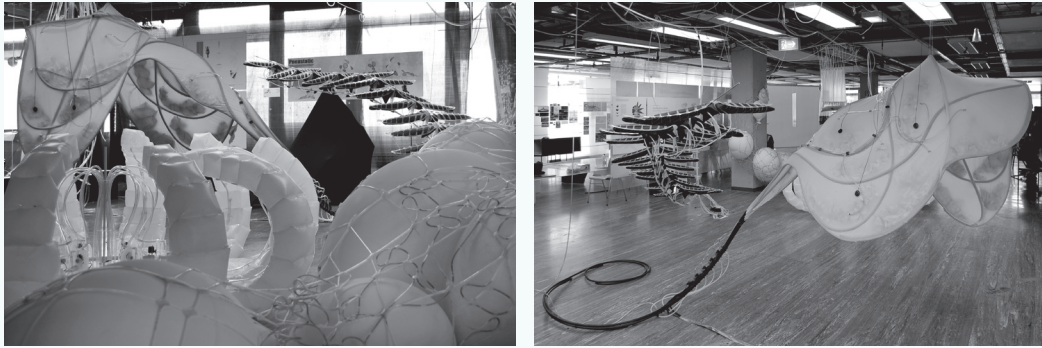
Therefore, most top-down criteria and evaluation protocols that have been put in place to categorise, analyse, test, and criticise architecture, for example function (programme, programs), order (form, style) or process (narratives, protocols), cannot but fail to withstand critical observation. Function as substantiation rationale for example does not really provide a valid analytical system. It is right that *“the behaviour of people, their judgments and assessments as ‘consumers’ of the building, the characteristics of their spontaneous alterations to the spaces, the symbolic situations they interpose into them, the texts of decisions they make”* belong to the *“operational*



▲ Figure 1 A series of Rapid Prototyped and laser-cut models researching contemporary re-interpretations of religious and sacral building typologies with digital technologies, Exuberant and Sublime Flesh, Unit 20 participation at the Austria Pavilion at the Giardini, Venice Architecture Biennale 2010.

knowledge” of the architect and are to be absorbed directly into the design processes, as argued by M.R. Savchenko (1980 pp. 31-39). The architect is to “define the characteristics whose value it will be necessary to measure” and to consider the “relationships and connections between the parameters themselves”. But both the functional parameters, to Savchenko the “direct measurements” of a building (“that is of its spaces, the architectural activities it accommodates, and of the consumers involved”) and the functional properties, the “indirect measurements of different readings, meanings and reactions inferred by an ‘intermediary’ consumer” (a “user who enters into the ‘make-up’ of the actual buildings”; some overlaid “symbolic situations”) end up being too ephemeral to predict, with functions and programmes changing too often and too radically to become absolute. One consequence of this variability and unpredictability is that parameters and properties as attributes become too fixed, and inadequate as evaluation criteria.

Perhaps this is why “performativity” seems to have replaced the word “function” in many architectural schools. Method-based processes and techniques surely make invention and originality possible, as they enable the implementation of technology, materiality and rigour, advancing the discipline’s knowhow. Nevertheless, they are perhaps too subjective and too closed, too often contingent on habit, familiarity and repetition and eventually run out of steam if regularly and repeatedly employed. In terms of order, stylistic canons eventually lose their validity, too. In classical architecture, perfect proportions were key criteria for beauty. The golden section, the golden ratio or the golden angle are well known, but hardly in use today (did you genuinely remember that the first is the number 1.6180339887, and the latter measures 137.5 degrees?); symmetry, rhythm and proportions are rarely discussed in a contemporary architectural context.



▲ ► Figures 2.1, 2.2 Bio(tro)nic Gardens, student projects by various first year students (Colletti studio first year BSc at the Institute for Experimental Architecture, tutors: Georg Grasser, Peter Griebel, Daniel Luckeneder, Markus Malin. University of Innsbruck, 2012). A plethora of pneumatic installations drawing on bionic and mechatronic references.

Without any valid top-down binary good-bad valuation principles, what we are left with is total insecurity, but therefore with the possibility to be creative. As Italian photographer Oliviero Toscani (2011, YouTube) states:

“Creativity is the consequence of a cultural action. That’s all! One does something, and people comment the result, “well, it’s creative”. Because it is new, because it was done with the courage to do things, to experiment on a new path. [...] Creativity is based on, is the result of, something done with total insecurity! A real creative is total insecure of the result.”

As an educator, I ought to assume the responsibility to convey the innate and fundamental capacities of a designer to create now and into the future. Design-research is definitively related to premonition, but is truly motivated by individual observations, decisions and insecurities. De-sign assumes the Latin signum [sign] (Flusser, 1999 and Hill, 2006 pp. 33-39). We could mention the synonyms “project” (from *prōicere*: to throw forward), and the similar mind-set expressed in the German word *Entwurf*, rooted in the verb *werfen* [to throw]. As Coop Himmelb(l)au explains: “We break up the word ‘Entwurf’ (design) into the syllable ‘ent’ and the word ‘wurf’ . Ent-wurf (de-sign). The prefix ent as in ent-äußern, to renounce, or ent-flammen, to stir up. Wurf like werfen, to throw” (Kandeler-Fritsch, M. and Kramer, T. eds. 2005, pp. 20-21).

BOTTOM-UP PEDAGOGICS

A child trying to make a kite fly; a boxing trainer shouting encouragement to his pugilist from outside the ring; English teacher John Kipling (played by Robin Williams) inspiring his students standing on a desk to discover their love for poetry and seize the day – these are on the other hand examples of (again literal) bottom-up scenarios for facilitating someone, or something, to progress, to grow, to overcome a difficulty, to fight fear, to be curious. I mention the kite analogy as it promotes a system of interaction and dependency based on paramount criteria for contemporary educational models: dynamism and openness. The kite needs the right environmental conditions – i.e. wind, open fields – and an agile controller to fly. The boxing trainer on the other hand may signify what I consider an up-to-date approach to education, based on coaching rather than teaching. The scene from the 1989 drama film *Dead Poets Society* is inspirational to me, too.

In one of the most memorable scenes, English teacher John Keating solicits his class to open their books by Dr. J. Evans Pritchard Ph.D., a fictional character (Arcadio's Weblog, 2009) on page twenty-one of the Introduction, and asks one of the pupils to read aloud the opening paragraph of the preface entitled Understanding Poetry:

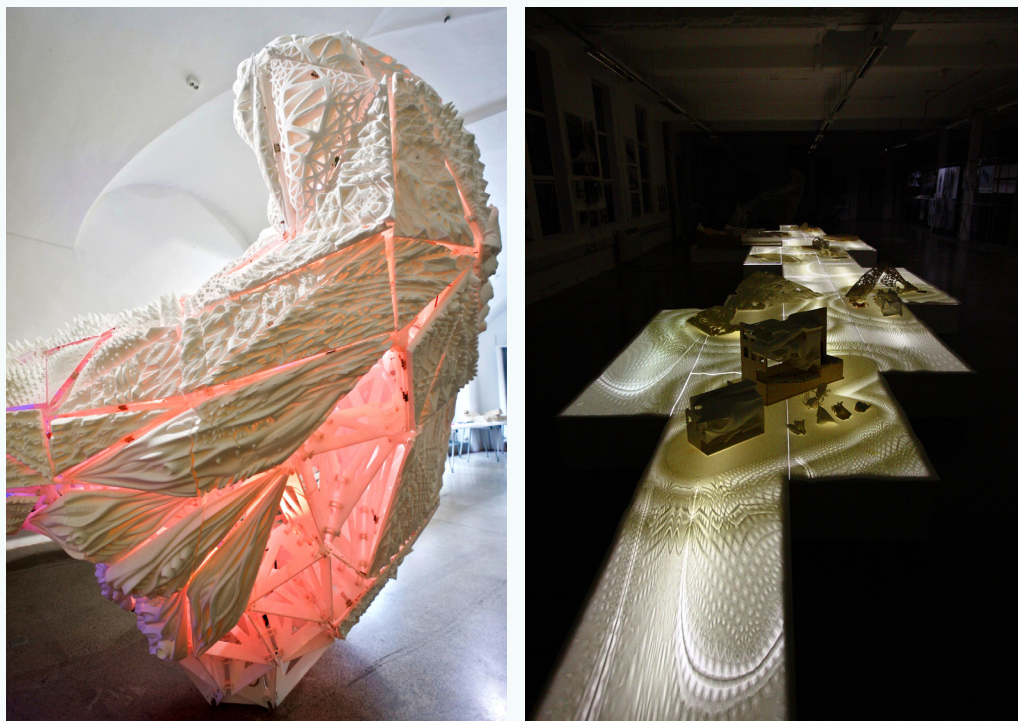
"To fully understand poetry, we must first be fluent with its meter, rhyme and figures of speech. Then ask two questions: One, how artfully has the objective of the poem been rendered, and two, how important is that objective. Question one rates the poem's perfection, question two rates its importance. And once these questions have been answered, determining the poem's greatness becomes a relatively simple matter."

If the poem's score for perfection is plotted on the horizontal of a graph and its importance is plotted on the vertical, then calculating the total area of the poem yields the measure of its greatness.

A sonnet by Byron might score high on the vertical but only average on the horizontal. A Shakespearean sonnet, on the other hand, would score high both horizontally and vertically, yielding a massive total area, thereby revealing the poem to be truly great. As you proceed through the poetry in this book, practice this rating method. As your ability to evaluate poems in this matter grows, so will – so will your enjoyment and understanding of poetry."

To which Keating, having drawn the graph onto the blackboard, replies: "Excrement! That's what I think of Mr. J. Evans Pritchard! We're not laying pipe! We're talking about poetry. How can you describe poetry like American Bandstand" (American Bandstand, 2016)? Eventually, he requests the students to rip out the offending pages, encouraging them by the words: "Armies of academics going forward measuring poetry, no! We will not have that here. No more Mr. J. Evans Pritchard. Now in my class you will learn to think for yourselves again. You will learn to savor words and language." What follows is the scene where he asks his students to step onto his desk to gain a different viewpoint of the class in order to open their mind. In my opinion, this passage from the movie epitomizes exactly that bottom-up and poetic understanding of teaching architecture that I am advocating.

Since we have put aside top-down criteria such as mind-independent parameters (with intensive and extensive attributes), user-centric properties (reactions and emotions), processes and stylistics order/s, we may now draw our attention to potential bottom-up alternatives. For example, capacities (open-ended interactions and interrelations with other material bodies), and tendencies (the possibility of variation, adaptability and change). Manuel Delanda (2009, p. 12) suggests that capacities "are different from properties in that capacities are always relational." Plus, capacities are more important than properties, given "that the number of things that may be combined with and interacted with is potentially open-ended", unlike properties, which are finite in number and always given. Properties, on the other hand, "despite the fact that they are given and that they can be listed finitely, are also subject to what might be called tendencies. The tendency of material entities at certain critical points of a condition allows a change from one set of properties to another." Such conditions of variability, openness and changeability are also inherent to effects, affects, haecceities and phenomena. Effects are caused by agencies and are, in Jeffrey Kipnis' ('The Cunning of Cosmetics', 1997) words, more "visceral than intellectual, more atmospheric than aesthetic" impressions. Affects on the other hand refer to symptoms, to emotional changes. A haecceity, on the other hand, is a term "from medieval philosophy first coined by Duns Scotus which denotes the discrete qualities,



▲ ► Figures 3, 4 ARC(2)himera installation, by Bartlett UCL MArch GAD Colletti research cluster 2, with Guan Lee, Tea Lim, and Pavlos Fereos 2012. Each student's pattern was developed in relationship to an individual project and to its neighbours. If completed (it stopped at 80%), it would be made of 7200 knots, 600 triangles, 90 m² skin, 20 pieces of Perspex, 7200 mini laser bits, 1200 joints, 350 rubber bands and 14400 metal pins. The Talented Mr. Ripply, by Bartlett MArch GAD Colletti research cluster, with Guan Lee and Tea Lim 2012. A 16 m long CNC milled ornate and translucent surface.

properties or characteristics of a thing which make it a particular thing ('Haecceity', 2016). And which makes a student a particular student. Phenomena may also appear in this list as such occurrences, experiences, neither purely object-related characteristics, nor virtual potentialities are embedded within a feedback system of events and observations, of language and hence of communication.

With such bottom-up criteria it follows that a main characteristic of design engagement must be variability – and therefore I advocate openness, approximation, dynamism and hybridity as being appropriate responses and strategies towards educating architects. Coaching (not teaching) a student is a *dianoetic* process that proceeds by reasoning, argumentation and contemplation (by research). It requires reciprocal communication, two-way debate and cooperative dialogue.

POETICS OF PEDAGOGICS

Arguably, such *modus operandi* of research-led education can only happen and thrive on an open and “multivalued” platform (call it a unit, a studio, a lab, a cluster, an institute, a centre, a school or a faculty) and not at a similarly conservative institution, such as the Welton Academy in Vermont in 1959 where the abovementioned movie is set (poor Mr. Keating got fired, after all). In an open bottom-up pedagogic domain exchange and growth are nurtured. Everybody is asked to partake in researching and challenging the

risks, the unknowns and all indeterminacies of the past, the present and the near future. As Umberto Eco (1989) writes:

“Multivalue logics [...] are quite capable of incorporating indeterminacy as a valid stepping-stone in the cognitive process. In this general intellectual atmosphere, the [...] open work is peculiarly relevant: it posits the work of art stripped of necessary and foreseeable conclusions [...].”

When he writes “the work of art”, we may read: the work of architecture, or the work of education. Research-based architectural education must promote such open working conditions: architecture is an “anexact” discipline (Lynn, 1998, p. 41). Consequently, students should be allowed to define their own projected trajectories “stripped of necessary and foreseeable conclusions”. Whilst tutors should not follow established and partly mummified academic models of indoctrination and should not fear to foster curiosity in their students. This approach is experimental but risky. Thus states James Cameron (‘Before Avatar...a Curious Boy’, 2010), the American movie director:

“What are the lessons learned. Number one: Curiosity. It’s the most powerful thing you own. [Number 2:] Imagination is a force that can actually manifest a reality. [...]. Don’t put limitations on yourself. Other people will do that for you. [...] Take risks. NASA has this phrase that they like: “failure is not an option”. But failure must be an option in art and in exploration, because it’s a leap of faith. And no important endeavor that required innovation was done without risk. You have to be willing to take those risks. [...] In whatever you’re doing, failure is an option, but fear is not.”

Thankfully fear is not an option, because an experiment is not only risky, but by default dangerous. Marcos Novak (2002) explains that there is a sense of danger in the meaning of the word “experiment”: the term derives from the Latin ex-periri [to test, to try], and periri from periculum, hence carrying the meaning of both attempt and danger. On the other hand, we could recount the term periculum itself to the Greek πείραν [peiran], meaning “that which is finite and can be experienced”. Experimental and experiential therefore lay closely together. Thus, individual, personal learning experiences are not a priori incompatible with collaborative, experimental scenarios.

Ergo, I would like to put forth poetics as a way to describe the making of an architect – an educational model that promotes a student’s individuality and nurtures her artistic and linguistic multi-voiced freedom of expression for differential interpretations of design intelligence. I am convinced that the concept of poetics and exuberance, which I have explored elsewhere (Colletti, 2013), stands in an intimate rapport to education. As Jan Turnovsky, I understand “‘excess’ as art, joy, imagination”, which are essential and yet ever so elusive qualities in many academic environments. I have already declared that, to me, design intelligence, architectural quality, and spatial intuition are not directly measurable, and hence not straightforwardly teachable. But I would claim that they can be researched on a platform of collaborative intelligence, network learning and distributed problem-solving.

Does this entail that poetics consequently present no “didactic character” whatsoever? I should emphasize that poetics is not used as synonymous to poetry. Etymologically, poetics stems from the Greek term ποιεῖν [poiein – to make]. If poetry is the form of literary art, “in which language is used for its aesthetic and evocative qualities in addition to, or in lieu of, its apparent meaning” (‘Poetry’, 2016), poetics is related to making, production.



▲ Figures 5.1, 5.2 Robotic FOAMing, workshop at the SmartGeometry 2013 event, the Bartlett UCL by the REX|LAB team [tutors: Georg Grasser, Kadri Tamre, Allison Weiler of the Institute for Experimental Architecture, University of Innsbruck, 2013].

This rapport is profound, as it is described in classical terms by Aristotle in his *Metaphysics* as the act of production following the thinking, *noesis*, as well as further strengthened by Plato to knowledge and by Aristotle to reason. In addition, poetics should foremost be linked to strategy. Turnovsky (2009, pp. 43-51) reminds us that, to Eco, poetics is similarly understood as “the form and structural plan of a work”, and “the artist’s operational programme”. He reinforces this by including the related concepts of “work-plan” and “work-analysis” to its meaning. What this elucidates is, that the goal of poetics is “to provide a means to ‘infer, from how a work is made, the way in which the work wanted to be made’”. He writes:

“The rational nature of the process of work-analysis itself, combined with the assumption that rational (intentional) elements exist within the object of analysis, lends the classical notion of poetics a constructive-logical aspect, which in turn allows it to be projected onto architecture in an almost exemplary fashion.”

I am aware that poetics as pedagogic strategy for research-led education may come across as too idealised, too intuitive [rooted in the Latin *intueri* [meaning look at, consider, perceive directly without reasoning]], or even too romantic. Indeed, strong eighteenth century romantic nuances, such as “*idyllic*” or “*picturesque*” are attached to the term poetics. Yet as Turnovsky states, “even in the emotionally charged Romantic period, the term poetics did not lose its association with reason”. If Novalis formulated: “poetry = art that stirs the emotions”, he also stated that poetry evoked “not only ‘moods’ and ‘visions’ but also, perhaps, ‘mental dances, etc.’”; and thus the emotions “referred to by Novalis are not part of the specifically sensual faculties (sensitivity, feelings, urges), but fall under the rubric of the mind (thought, emotion, will).” This sustains my claim that poetics as strategy is a process that can be discussed, communicated and evaluated as pedagogic process for providing a framework for research-led education in the 21st century.

REFERENCES

- Cameron, J. 2010, TED, ‘Before Avatar...a Curious Boy’, https://www.ted.com/talks/james_cameron_before_avatar_a_curious_boy?language=en, filmed Feb 2010.
- Colletti, M. 2010, (guest ed.) *Exuberance: New Virtuosity in Contemporary Architecture*, Architectural Design, Chichester: John Wiley & Sons, profile no. 204.
- Colletti, M. 2013, *Digital Poetics. An Open Theory of Design-Research in Architecture*, Farnham UK and Burlington USA: Ashgate Publishing Limited.

- DeLanda, M. 2009, 'Material Evolvability and Variability', in Lars Spuybroek (ed.) *Research & Design, The Architecture of Variation*, London and new York: Thames & Hudson.
- Eco, U. 1989, *The Open Work*, trans. by Anna Cancogni, Cambridge, MA: Harvard University Press.
- Flusser, V. 1999, *The Shape of Things: A Philosophy of Design*, London: Reaktion.
- Hill, J. 2006, *Immaterial Architecture*, London and New York: Routledge, pp. 33--39.

Space & play time - the value of the speculative act in architectural design (education)

David Short

University of Nottingham, UK

INTRODUCTION

Across humanities and social sciences, there has in recent years, been a renewed interest in acts of speculation and their benefits to research and problem solving ['Speculative Realism' workshop at Goldsmiths College, London, in 2007, 'Speculative Realism and Speculative Materialism' conference at the UWE, Bristol April 2009, 'Speculative Art Histories' symposium, Witte de With Centre for Contemporary Art , Rotterdam, May 2013, 'The Art of Speculation' joint symposium, Berlin, November 2014 and The 'Speculative Tate' series of Talks and Lectures, at Tate Britain, London, October 2014 – May 2015]. Speculation at one time was considered one of the highest forms of thought. This paper seeks to promote the act of speculative drawing as an integral part of a design process and supports this by discussing and evidencing the work of studio Unit 4, at the Department of Architecture, the University of Nottingham. This undergraduate studio, has for many years been interested in exploring and developing creative methodologies in architectural design education, that broaden the conceptual range by which architecture is produced. This is not so much about having an idea that conceptually challenges or provokes, or indeed about the finished object that may challenge and provoke, it is the process of the speculative acts in drawing that are the focus of attention; producing drawings that become territories and landscapes for thinking and speculation. This speculative approach over many years has encouraged, fostered and often created unique architectural outcomes that are unexpected and very personal. Underscoring the work lie the fundamental principles of drawing and thinking, questioning and reflecting; principles that enhance a student's capacity for creative problem solving in an open and exploratory way.

THE SPECULATIVE WHAT?

So what do we mean by a speculative act and in particular the speculative drawing? What might inventive speculative practices look like in the design studio? These are some of the questions that this paper will consider.

Fundamentally this approach demands an 'exploratory form of engagement', as the Unit of Play at Goldsmiths (The Unit of Play, Department of Sociology, Goldsmiths, the University of London) might



▲ Figure 1 Mark Freeman, untitled, graphite, charcoal, ink and water colour paint, size A2

put it, but instead of the ‘development of experimental, interdisciplinary and inventive modes of thinking and inquiry in the social sciences’, the application here is to the pedagogy of the design process and the production of architecture. Instead of, or as well as, putting ‘ideas into play’, it is about putting play into ideas.

This paper is therefore about the performative side of speculation and does not attempt to consider its theoretical situation. However, it does support the reconceptualising of problems and the seeking of more imaginative propositions. The processes being discussed also require the continual asking of questions, particularly the ‘what if’ question? These processes demand risk taking and a belief and commitment to being curious and inventive. The risk here is being prepared to take a leap into the unknown. The speculative act engages students of architecture, specifically with the notion of enquiry through what one might call an ‘improvised thinking drawing’. In this way, and above all, it is a process designed to explore and broaden an approach to design and to find different and particular ways of doing things. Students work at this interface between the idea and the drawing; a position of great liminality and potential; a place where things become interesting.

The speculative act stems initially from the imagination and then demands critical reflections as the process continues. The act is made without dogma, prejudice or preconception. It is a stepping off point into an unknown place. Through this process of speculating by drawing, a subject is opened up interrogated and then released. These drawings are about study and research not graphic illustration. We are trying



▲ Figure 2 Alice Chadwick, *Absent Identity*, charcoal and pencil, size A2

to study and speculate within the drawing. As a consequence, the work is fresher and more engaging through its incompleteness and the ability to read into it many things (speculation). The speculative nature, the content, the process of study through drawing and the narrative, these are where ideas are worked out, not represented.

Peter Zumthor in his first lecture delivered in English at the Southern California Institute of Architecture, (November 1998 <http://sma.sciarc.edu/video/peter-zumthor-2/>) spoke about ‘preliminary promises’ in drawings and that he liked drawings that “reach out to the reality of the object”, referring to “permeable spots which allow for our imagination to enter and our curiosity about the reality to flare up.”

The speculative drawing is done to establish possibilities as well as priorities and to find an architectural

vocabulary; drawings that translate thoughts, research and feelings. Sometimes conjectures are uncertain and sometimes assured. Although most architectural drawings are done to have an impact on the intended observer or to provide specific pieces of information, this is not so important here. These drawings attempt to capture the spirit and essence of the work; “the stuff of angels” as Ted Cullinan once observed (Cullinan, 2006).

The speculative drawing encourages and allows freedom to explore and express a thought or an idea. The speculative drawing seeks to find an authenticity and essentiality to an architecture project. It seeks to release the full architectural potential and meaning and to capture the mood and the moment.

It is vital that these drawings remain in the realm of the duality between reality and imagination. They set particular and peculiar touchstones and hold great richness and a sense of potency from which architectural propositions follow and against which later designs can be constantly checked. They are reference pieces for studies that follow.

THE SPECULATIVE WHY?

The approach of speculation by drawing is intended here to assist broadening the conceptual range by which architecture is produced. Within the praxis of architectural design, finding space for speculative acts is difficult and questionable. These processes

require more time and are demanding. However, students studying architecture have a privileged position and should be encouraged to use it. Merritt Bucholz, speaking at the Utopian Studies Symposium in 2013 (Professor Merrit Bucholz at the University of Limerick) described the studio space as “.... a space of doubt. This is not a space of answers; this is a space of questions. This is a space of experimentation. This is a laboratory, but above all it is a space of doubt.”

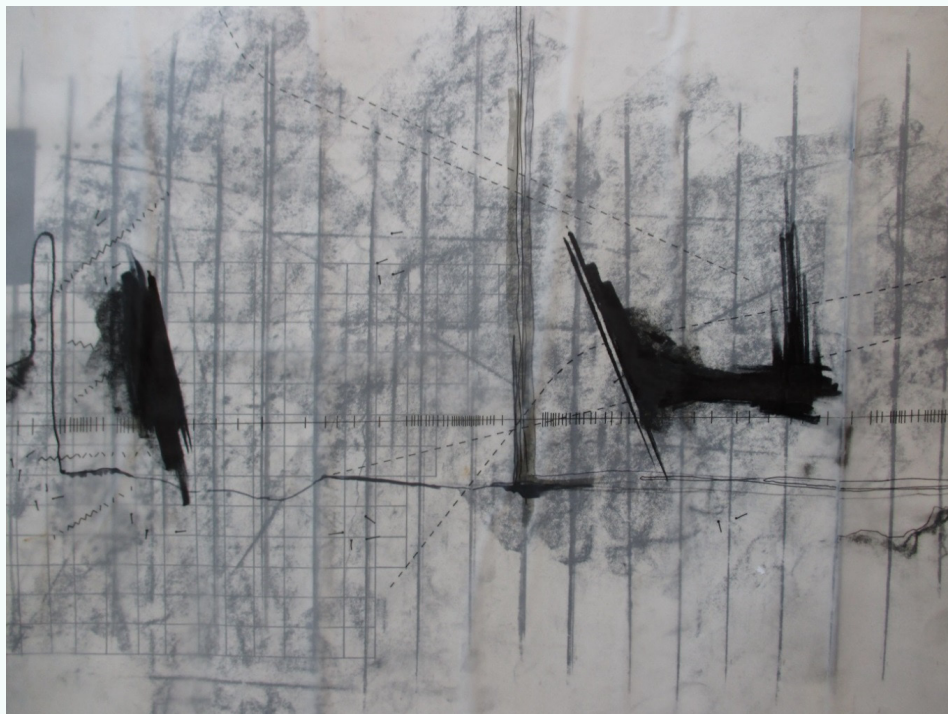
In an increasingly challenging architectural educational environment of constraints imposed by universities, ARB/RIBA prescription of validation criteria and EU Directives, it is important to still find space for diverse approaches to solving design problems. In the practice and learning of how to design, speculative approaches that push at the edges or through these constraints are of use. Linked to this is the need for students coming into university education, and in particular to study a programme such as architecture, to free up and value new ways of thinking.

The nature of a speculative method, in what is an increasingly dynamic and complex world of architectural design and practice, seems not only appropriate but potentially rewarding in a way that the traditional iterative singular approach cannot. It is inherently flexible as an approach and adaptive. Can we persuade that this is a ‘productive mode’ of thinking and this method of speculation when used as an integral part of the design process has the ability to create particular and special pieces of architecture?

One of the most important aspects of architectural education is the instilling in students of an ability to think and reflect critically about the work in hand. Encouraging and fostering an enquiring, thinking and critical design methodology must be paramount. This is at the heart of working speculatively. As we will see it is not only about the need to play or explore creatively and freely but equally important is the need to reflect and question critically.

It could be argued that designing a building is in itself a speculative act or at least it should be. When a building becomes part of a catalogue of products and processes, it will inevitably have lost something. Could a speculative approach to design, alongside the traditional iterative singular approach, add significant value in an increasingly complex, fluid and dynamic practice environment?

We have found in practice, in the design studio, that it is not only the accomplished students who benefit from these processes. The students who are still finding their feet with designing architecture are often able to produce a piece whether drawn or made that has real quality about it. This will not be a building and so the student’s inherent weakness in their ability to progress with a normal design process is not exposed at this key stage. However once this piece has been done it ‘traps’ the clues of a successful outcome and becomes the touchstone against which the future design can be checked and measured. Does the design, as it progresses, retain the key characteristics of the touchstone drawing? Does it achieve the things that the work so eloquently spoke about? Students can measure how their work is progressing. This is an understandable process. For the more able student there is a sense of a different challenge and an extending of skills by a broadening of their thinking and approach



▲ Figure 3 Detail from an exploratory speculative drawing, Avneesh Poonia, Arianne Dermawan & Emily Cowles, untitled, Charcoal (black and white), Charcoal (black and white) and water mix, Acrylic paint (black and white), Marker pens (black and brown), Fine liners original size 3 x A1

that in turn produces a richer outcome. These are challenges that we believe are worthwhile. The drawback for the students is that this approach takes additional time in an already demanding schedule; a schedule that can be rigid in its application. It therefore requires a sense of confidence and trust shared mutually between student and tutor in the process. From left and right, the students, who will be exploring and speculating, will also have technical demands made upon them and will need to justify their strategies and functional rigour, perhaps at a stage when they will be more exposed and uncertain. It is to their credit that the nature and quality of the work, having navigated through such demands, has been acknowledged by Departmental awards and by inclusion in exhibitions at the RIBA and the Royal Academy.

THE SPECULATIVE HOW?

The speculative act promotes the idea of enquiry and reflection. In Unit 4 this speculative questioning of ‘what if?’ and then the critical reflection, is done through drawing. The speculative drawing is a free ‘abstract’ drawing through which a thought or an idea is explored and expressed. So how is this done and what does this look like in practice?

The speed of the initial drawing is important. The time taken could be as short as 7 or 10 minutes or it could be done in a day’s workshop. The media used for the work is also important in that it should promote the freer or broader approach. Charcoal, pastels and broad brushes are useful as is papier collé.

By fostering and promoting a sense of play and encouraging working quickly, we



▲ Figure 4 Detail from an exploratory speculative drawing, Avneesh Poonia, Arianne Dermawan & Emily Cowles, untitled, Charcoal (black and white), Charcoal (black and white) and water mix, Acrylic paint (black and white), Marker pens (black and brown), Fine liners original size 3 x A1



▲ Figure 5 Detail, Emily Cowles, Charcoal (black and white), Charcoal (black and white) and water mix, Acrylic paint (black and white), Marker pens (black and brown), Fine liners

try to remove inhibitions and generate an intuitive, subconscious initial response. Preconceptions are discouraged and avoided. Students talk about a ‘gut instinct’ or the need to ‘get it down’ on paper or of ‘letting the hand go’. These responses are setting out starting points that search for the essence of the project. It is important that the drawings establish an ambiguity. We might refer to these as abstract drawings.

Clearly the first drawing can be made in response to the initial briefing. This can be followed by a response to a site or other key influences on the project at this early stage. These responses could be combined in one drawing. These drawings act as stepping stones into a project. At key stages through the design project other speculative drawings are encouraged. These are done to unlock a solution to a problem or to respond to an important more detailed component of the work.

The notion of play is important. Play suggests a creative freedom, free to play, to open up and broaden the approach. Play relieves the tension or straightjacket of the need to produce. This in turn breeds a confidence that can be carried through into the design process. The approach at this stage is not precious and therefore, working alongside each other, students feel comfortable in discussing their work and what they are trying to achieve. In turn, this confidence is taken forward when more specific, detailed, perhaps more difficult conversations are required, concerned with the nature of the architecture. These characteristics breed confidence in the student and their work. It becomes a personal thing and therefore also an emotional thing. With this attachment comes an ownership.

It is always good to jump in and play and to work quickly, but if this process appears too daunting, students can be led through a series of preliminary works that may lead on to larger drawn pieces. This process would include postcard-size drawings acting as cartoons, in the traditional sense, to prepare and guide the larger drawings. The larger drawings are the main setting of the speculation.

One might understand this as a speculative method of working through play and time



▲ Figure 6 Bob Cui Chang (Unit 4 Yr. 3 Student 2012/13), media not known size A3

and the freedom that it generates. As important is the next stage of stepping back from the work before returning and questioning it.

Perhaps of interest here, is that in spite of the student being the author of the piece, its technique and its content, it is still possible and important for the student to question it by always asking what if? This is where speculation continues. What if I read that part of the drawing in a different way? What if I read the drawing as a section and not a plan? What if I move the ground position from here to here? What if the scale moves from 1:50 to 1:500? What lies within the blackness of the shadow? This ability to question a work in this way by its author brings a new dimension to the process and a real sense of speculation. It constantly asks the student to question everything. The drawings now become 'questioning drawings'.

Discussions open up into unexpected areas that are not foreseen. Other areas of discussion to do with composition, balance and aesthetic judgement move to the front from the off, and an importance is placed on these criteria. Slowness is now useful with an attention to the detail and consideration of the results; what works and what doesn't? This is about judgement of the components and relationships and in the end composition; what is useful and what is not. The priorities of spatiality, light, dark and shade, rhythm and pattern can be useful points of focus. Other important references can be brought into these drawings, blocks or planes of colour that could be identified as forming the space within the view. One could then look for rhythms and structures within the composition. Students will also look at the pieces to see where the eyes go

or to find the noise of the drawing before filtering out its content.

As a further example, in Bob Chang's drawing (figure 6.), we are immediately invited to conjecture on what is happening. There are clear juxtapositions of scale. We are uncertain as to whether parts are sectional or shown on plan. There are components that could be structural, others that may be beautiful objects or places of enclosure. Overall there is a certain consistency and quality in the drawing and its vocabulary; no mean starting point for any building.

It is comparable with the task of interpreting a client's brief, except that in this case we are dealing with a search that is not immediately for the plan or section of the building on the site but for a potential that the building might have. The drawings are therefore loose and speculative in nature. The drawing in this way is above all a thinking process designed to explore and to find a very particular way of doing things. If one thinks too hard about where to put a line there is nowhere to go with it or to play, or alternatively if one thinks too hard before committing to paper then a number of possible options or scenarios may be discounted without ever exposing these to play and speculation. Thrown into the mix are exercises in responding to music, situation and brief. Improvisation in music and to a musical piece enhances the experimentation and play-feel as well as demanding a response. The speculative how is practised. The use of the monoprint technique in printing, with its structured unpredictability, is both discussed and tried. Here the understanding of the 'controlled chance' is acknowledged and embraced.

Of specific importance is the extent to which speculation is used, and the ability to keep this process open for as long as possible. The drawing becomes a touchstone piece, to be referred to on a regular basis, as the project develops.

Does the project still contain the essence and character of the speculative drawing? What has been lost and why? Why can't I get the quality of that drawing into the project? These are critical reminders and references. This is more work, difficult work and translating these 'what if' drawings into an architectural proposition is also not easy. It demands commitment, belief and a confidence that there is something there worth looking and working for. Perec, in particular, teaches us that if we are not seeing anything interesting then we are not looking hard enough (Perec, 1975). The architectural project becomes much more of an emotional experience.

These processes are challenging and demanding, and require additional time outside of, or in parallel to the iterative analytical process. The translation of this information into drawings that have architectural characteristics is equally challenging.

It is clear from discussions with students that there is a strong feeling that following a more straightforward design approach, for many, sets up a series of hurdles or even barriers that have to be negotiated. It is often possible to get stuck at these positions. With a freer approach from the outset the route does not feel full of such obstacles and even if one presents itself, because of the broader approach that has been taken, it feels easier to find a way to deal with it.



▲ Figure 7 A still from the video 'Blues for Miro' (1966) – an improvised piece by Duke Ellington, https://www.youtube.com/watch?v=0CZWq0YiM_U



▲ Figure 8 An improvised 7 minute drawing in response to Duke Ellington's 'Blues for Miro', Raluca Sozanskyj, Unit 4, Shaping Sounds, 2B Pencil, charcoal, soft coloured pastels, black felt tip pen, size A3



▲ Figure 9 Hannah Millar, detailed study, media not known, size A3

This process fosters a greater sense of ownership over the work. Each student will make the drawing in their own way using their own media. There is a feeling that the outcomes not only of the speculative pieces, but also of the finished building projects contain a sense of the student's personality. Thus, the outcome can be said to be more personal and particular.

Students are not replacing any recognisable sequential design process, nor are they replacing fact with fiction; their projects still have to work and be buildable, and these studies are done alongside a sequential process, not instead of one. However, the uniqueness and personal claiming of their projects by individual students is impressive.

Gaston Bachelard in *Poetics of Space* states:

"Thus we cover the universe with drawings we have lived. These drawings need not be exact. They need only to be tonalized on the mode of our inner space. But what a book would have to be written to decide all these problems! Space calls for action, and before action, the imagination is at work. It mows and ploughs. We should have to speak of the benefits of all these imaginary actions." (Bachelard, 1957)

And so what lessons for architects or students of architecture? We learn that if we do take an approach that demands constant observation and study through drawing it can be useful. With these tools, architectural design, when successful, can have a range and breadth to it that is not glibly and blindly reproduced without thought and without meaning. That working quickly to avoid preconceptions and

dogma is helpful. With students there is an acknowledgement that these processes breed a confidence not only in their skills but also in their readiness and their ability to engage with a discussion of their work. The processes enhance the creative acts in architectural design including focussing on composition and aesthetic judgements. And perhaps as important as any, students take ownership of their work and believe that there is something of their personality in the finished projects.

Finally, the Unit is interested in how can we enhance what we are already doing? What can be learnt from other disciplines where speculative work is being done? How can we apply the theoretical positions behind speculation within the unit? We are interested in exploring at which other points in the design process or indeed the practice of architecture, can speculation be applied and be helpful? Are there other ways of speculating that might also be worthwhile? Perhaps, it is after all, an aid to producing buildings that might in some way mean more, have greater relevance and even have the ability to move us.

REFERENCES

- Aragon, L. trans. by Watson-Taylor, S. (1980) *Paris Peasant*, London: Pan Books. Bachelard, G. trans. by Jolas, M. (1992) *Poetics of Space*, Boston: Beacon Press.
- Cook, P. (2008) *Drawing the Motive Force of Architecture*, Chichester: John Wiley & Sons.
- Darden, D. (1993) *Condemned Building*, New York: Princetown Architectural Press.
- Dunne, A. and Raby, F. (2013) *Speculative Everything, Design, Fiction, and Social Dreaming*, Cambridge Massachusetts: MIT Press.
- Lim, C.J. / Studio 8 Architects (2011) *Short Stories: London in two-and-a-half dimensions*, Abingdon: Routledge.
- Perec, G. trans. by Lowenthal, M. (1975) *An Attempt at Exhausting a Place in Paris*, Cambridge Massachusetts: Wakefield Press.
- Perec, G. trans. by Sturrock, J. (1997) *Species of Spaces and Other Pieces*, London: Penguin Classics
- Pallasmaa, J. (2009) *The Thinking Hand (Architectural Design Primer)*, Chichester: John Willey & Sons.
- Pallasmaa, J. (2012) *The Eyes of the Skin, Architecture and Senses*, Chichester: John Willey & Sons.
- Online Source Material:
- Dutton, T., Koch, A., Schwennsen, K. & Smith, D., *The Redesign of Studio Culture*, The American Institute of Architectural Students, Dec. 2002. http://archdesign.vt.edu/students/images/Studio_Culture_Report_2002.pdf
- Zumthor, P. (1988). *SCI-Arc Media Archive: Southern California Institute of Architecture*. <http://sma.sciarc.edu/video/peter-zumthor-2/>
- Bucholz, M. (2013) <https://www.youtube.com/watch?v=kw1pNQwML08>
- With thanks also to Unit 4 students: Alice Chadwick, Arianne Dermawan, Mark Freeman, Jenny Hall, Rachel Li, Max Mackay and Jessica St Claire for sharing their views with me.

Fieldwork

Simon Herron & Susanne Isa

University of Greenwich, UK

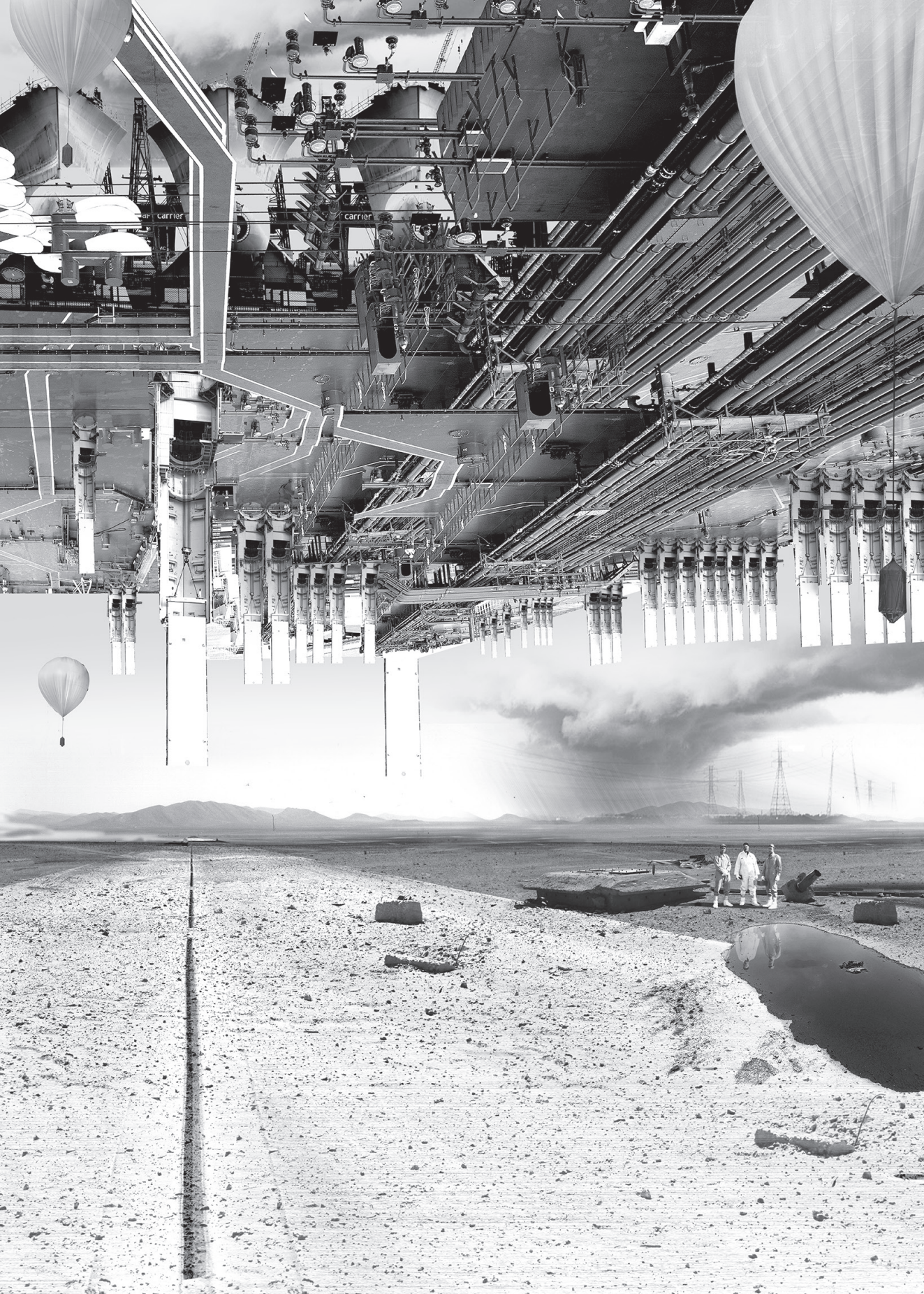
“Instead of causing us to remember the past like old monuments, the new monuments seem to cause us to forget the future. Instead of being made of natural material, such as marble, granite, or other kinds of rock, the new monuments are made of artificial materials, plastic, chrome and electric light. They are not built for the ages, but rather against the ages.” (Smithson, 1979).

The Anthropocene nature subjugated, relocated to the zoomorphic juncture of pure metaphor - a romanticised fictional image of self. At the intersection of postmodernity, everything that was once stable appears to have become uncertain. The powerful interplay between the forces of nature, and technology, against those of culture and economics - construct strange distorted picturesque futures - affected foreground, mid-ground and background. This shift of mankind from passive third-person observer of planetary systems and events, to that of central protagonist and principal architect of planetary change, underpins the growing argument that we have unwittingly precipitated and crossed an epoch boundary into a new geological period.

Air-Plain Continuous Construction No 01: Above the man-made Playa of the test site, in a state of total arousal. Air-Plain, a vast labyrinthine structure, a non-monument, continually evolving autonomous complex. A moderate Utopia - plugged, clipped, jacked, hacked, tuned-up, mashed-up, a wired-in - total consumption machine. Within the expansive field - an illusory environment of intricate data systems, landscapes of unknown authorship and shared pathways. Buffer Zones - construct boundary layers to the peripheral of the visible. An understanding of the invisible is rendered through an examination of its inherent invisibility. Within, anthropologists wage ideological battles between objectivity and subjectivity, culture and text - systems of classification and disorder.

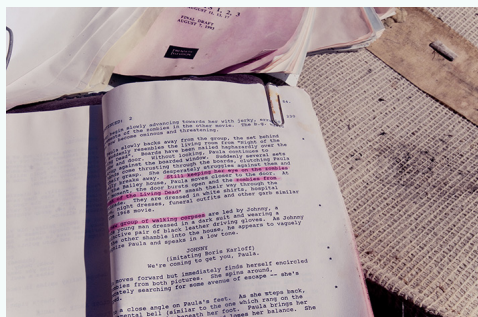
Fieldwork: This paper will reflect on the tools, practices and function of Fieldwork, defined as a primary analytical tool, central to architectural design studio culture. Presented as the practice of active, creative curiosity, a catalytic mechanism deployed to challenge preconceived readings and prejudices, to decode and reflect upon the familiar and unfamiliar alike. Within this expanded field, survey sites to sites of display, orthodox dialectic instruments of enquiry will be finely balanced against those of inexplicable paradox.

We will consider the observational manuals of Karl Baedeker, handbooks for travellers - to the romantic architectural wanderings of Mornings in Florence





▲ Figure 2 Amtrack - Station, Las Vegas, Susanne Isa 1994



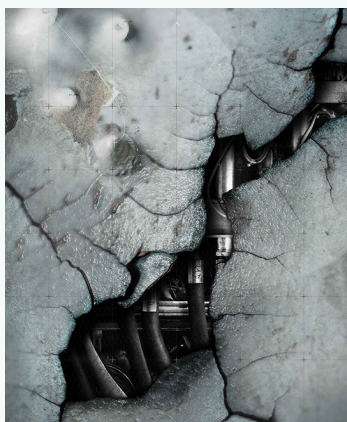
▲ Figure 3 Script - Palm Springs California, Susanne Isa 2010



▲ Figure 4 Swimming Pool - Nogales, Arizona, Susanne Isa, 1998



▲ Figure 5 Red Canary - An Incomplete Dictionary of Song Birds, photobook, Luke Stephenson, 2016



▲ Figure 9 Skin - Vahagn Mkrtychyan, Unit 16, University of Greenwich, 2014



▲ Figure 6 Oil - GAS TANK CITY - Andrew Holmes, colour pencil on paper, 534 x 762



▲ Figure 7 The Presidents Men - Petroleum Museum, Midland Texas, Susanne Isa, 2000



▲ Figure 10 Becks - Bremen, Germany, Susanne Isa, 2003



▲ Figure 8 Hello America - Simon Branson, Bartlett Unit16, 2000



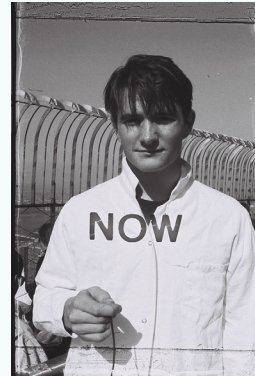
▲ Figure 11 ONE - GAS TANK CITY - Andrew Holmes, colour pencil on paper, 534 x 762



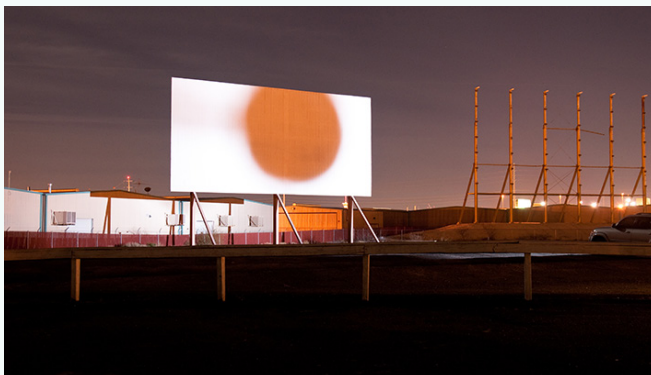
▲ Figure 14 NISSAN - Arizona, Susanne Isa, 2003



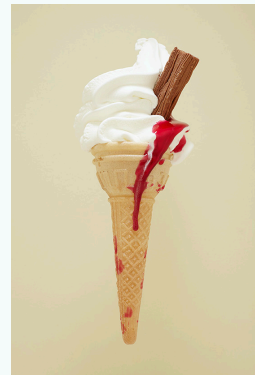
▲ Figure 12 Missile Park - Alamogordo, New Mexico, Susanne Isa 1994



▲ Figure 13 NOW- Mark Davies, Bartlett, Unit 4, 1994



▲ Figure 15 Drive-In - El Centro, California, Susanne Isa, 2010



▲ Figure 16 #56 Crosby - 99x99's photobook, Luke Stephenson 2015



▲ Figure 17 Trinity - Open house, White Sands Missile Range, NM, April, Susanne Isa, 2003



▲ Figure 18 Caravan - Bombay Beach, Salton Sea, CA, Susanne Isa, 1996

[Ruskin, 1881] or Learning from Las Vegas, or Form Analysis as Design Research [Venturi, Brown and Izenour, 1972]. What tactics, what methodologies can be imagined for the near future.

The Anatomy of Melancholy, “what it is, with all the kinds, causes, symptoms, prognostics, and several cures of it. In three partitions; with their several sections, members, subsections, philosophically, medically, historically, opened and cut up. By Democritus Junior [Robert Burton- author] with satirical preface conducting to the following discourse” [Burton, 1621]. An analogue compendium and guide book, a 17th Century universal model of everything. Compiled to account for and explain all human emotion and thought to date. No beginning or true end, a deliriously complex interwoven structure. Witches and magicians, the geography of America, digestion, the passions, drink, kissing, jealousy, or scholarship.

Fortresses of Solitude: Unorthodox landscapes of contemporary curatorialism – The New Wunderkammer. A taxonomy of meticulous facts, footnotes, exhibit cards, carefully catalogued listings, sources, and citations, provenance recorded, all supported by the reassuringly confident tone of the absent narrator. A delirious journey confronting complex strands of interwoven narrative and inexplicable facts; finally balanced on the edge of reason and bathed in doubt. Historical Arcane and Natural Curiosa originating in the private collections of 16th and 17th Century Europe, to the Museum of Jurassic Technology, Los Angeles; the expanding network of presidential libraries, powerful vitrines of state, immortalising past leaders into the new deity.

The Whole Earth Catalogue [Access to Tools]: Produced by Stuart Brand in California, in Autumn 1968, following the Summer of Love. Seen by many as the forerunner to the Google search engine. An analogue system produced with polaroids, hand typed, cut-up text on cheap paper. This was seen as a contemporary open source evaluation and access mechanism and user manual to the counter-culture of the 1960's. Like Burton's Anatomy of Melancholy, both present contemporary idealised worldviews, functioning as compendiums of thought and practice. Both attempt reconciliation of complex whole systems – or gestalt. From land use, communication, community, through ideas of nomadism and learning.

The Other Theory of Physics: A unified theory of mass, space and time, developed by the amateur physicist and trailer park proprietor Jim Carter. In an age of on-demand content, encyclopaedic inventories, and self-authorship, where everyone their own curator, in the shadow of Marshal McLuhan's Gutenberg Galaxy, an endless library of Babel, to the internet of things. In this new landscape where printed content remains largely unread – pointlessly aestheticized and stored. Technologies of agency evolve as seamless anthropomorphic haptic extensions of self – tirelessly, yet relentlessly exploring the world on our behalf. In the Anthropocene, sites are physical and immaterial, both are subjugated and experienced by our digital selves – outsourced and endlessly shared – to online content of Facebook and the cloud.

Camera House: An assemblage of a domestic environment with inhabitants and programme. The house as co-protagonist - registers mundane and imperceptible events in the lives of its inhabitants on its photosensitive surfaces - recombining and juxtaposing programmes. Various mechanisms constitute house - kettle switch, spilled coffee, elevated humidity - all involuntary triggers for specialised shutter-release. The kettle switch floods the dining room – illuminated for one thousandth of a second. The spilled coffee drains

through the floorboards starting an exposure that might last for ten years or more. The house is wired and chemically active - it is vivid and visceral - a collaborative involuntary proto-nervous system.

Gas Tank City: An anonymous architecture of transient structures – rigs, trailers, tanks, endlessly traversing the permanent infrastructure of the highway logistics system. 43,000 miles of hardtop – a single unifying militaristic entity of deep paranoia. Gleaming machines, constructed from mass produced industrial components – complex assemblies of hardware rendered visible with azure blue light. An architecture captured in momentary stasis – viewer unseen. Each image, the consequence of an elaborate transformative process. Light captured on 35mm film, carefully transposed to a solid paper ground, Derwent colour pencils, gradually build intense layers of super saturated colour. The resultant image a radiant melodrama of Californian light.

“...That stronghold which was to be my secret sanctum...My hideaway... The one place, perhaps, in the whole universe, where I can come to study...To contemplate... Or to simply relax... To shut out the whole world, and be alone...As every man needs to be at least once in a while... I remember how, years ago I first discovered this desolate spot – and returned later to turn that desolation to my advantage.”
[Superman introducing his incredible Fortress of Solitude – All new collector’s edition. DC Comics Inc., Summer 1981, DC Series Vol.5 No. 6].

REFERENCES

- Robert Burton, Priest and Scholar, *The Anatomy of Melancholy*, First published 1621, obsessively rewritten, revised and expanded in five subsequent editions.
- John Ruskin, *Mornings in Florence- Being Simple Studies in Christian Art For English Travellers*, First published 1881 - A detailed description of six journeys.
- Robert Smithson, ‘Entropy and the New Monuments’, *The writings of Robert Smithson*, Edited by Nancy Holt, New York University Press, 1979, [Artforum June 1966].
- Robert Venturi, Denise Scott Brown and Steven Izenour, *Learning from Las Vegas, or Form Analysis as Design Research*, First published 1972, original fieldwork undertaken with Yale Architecture Students in the Fall semester, 1968.

A series of 'happy accidents'

Victoria Farrow, Birmingham City University, UK

Stephen Garrison, Marywood University, USA

One of the main drivers to online teaching and learning in HE has been the strategic influence of HEFCE to embed a greater use of technology for enhancing learning, teaching and assessment (HEFCE, 2005/12) over the next 10 years. The term e-learning is a term used to describe the vast technological developments and approaches. It *"looks at how institutions can enhance learning, teaching and assessment using appropriate technology."* *"Enhancing learning, teaching and assessment through the use of technology is one of a number of ways in which institutions can address their own strategic missions."* (webarchive.nationalarchives.gov.uk)

INTRODUCTION

Students at any level of their journey through architectural education can find themselves at a loss when attempting to document their personal design process. It can be hard enough to construct and maintain a solid concept and presentation of the final proposal but to meet the expectation of tracking and recording the design development process whilst successfully communicating the design thinking behind the project, can prove to be a daunting challenge, particularly for those students at the beginning of their education. Similarly, it can be difficult for educators to fully appreciate the detail involved in the design investigations that derive outside the studio yet provide a critical explanation of the "final" idea pinned up on the wall. Many untracked studies can be lost, models crushed and sketches abandoned; I was interested to know more about what I had been missing out on.

Introducing "blogs" into the delivery of architectural education at my previous institution in 2012 marked the start of a series of "happy accidents"; a number of positive outcomes, unanticipated and unexpected results that have brought about many new practices and collaborations. Consequently online tools have now become a grounded and well-integrated part of my studio teaching. Through the use of blogs I have been able to construct an instantaneous connection between the students' personal design journey and the web, providing awareness for fast and diverse feedback, together with a way for me to assess the whole spectrum of the students' design ideas – rather than simply the end products. Blogging has enabled changes to be made to how the programme can be marketed, enabled connections to be fostered both locally and globally for various project collaborations, opened up new opportunities for public critique and also uncovered evidence which provides encouragement for continuing to explore the use of social media in studio in future years.

Through use of examples and experiences collected over a period of 4 years, this paper will present and evaluate how I have used blogs, beginning with the journey that I embarked upon in 2012 with the intention of strengthening

reflection in architectural education, assisting student communication of projects both verbally and graphically, to integrate more collaboration in studio with other design courses and also to provide students with the ability to create a digital identity for themselves both at university and upon entering the world of work. Following this initial evaluation, an overview of the events that unfolded as a result of a move to a blogging community will be given to highlight further advantages of this practice. The paper will then lead on to describe how these original discoveries were explored more deeply, following a visit to the USA in December 2014 which triggered an opportunity to further integrate the use of blogging into the studio and to test this technology in a different context, a different country and with different students. The second half of this paper will thus describe the outcomes that came about by introducing blogs and social media to an existing studio at Marywood University, USA and the questions posed and answered via this study. A description of how these have helped strengthen an understanding of how this technology can enhance the studio experience for students will be presented. This study and collaborative pairing which is still in place, has enabled both myself and my co-author to continue to investigate the use of social media in studio and to test different speculations such as whether it would be possible to utilize blogs as an extension to the 1:1 tutorials already in place.

BLOGGING

Introduced on day one at first year level 1 as a tool for recording and communicating ideas, blogs are now frequently seen in the upper years of the programme together with alumni of the school, who are now moving forward into their careers after education. There has been no question as to how useful the blogs have or will be to the students who have embraced this technology fully, and in hindsight I often wonder why I did not explore the use of a similar design tool earlier. Although not compulsory, the induction week prescribes an engagement with blogging technology to introduce the students to recording their design development online. From this point, blogs remain as a key part of the students' learning journey throughout the Level 4 programme. We discuss them in tutorials, students can present verbally with them as a structure for presentations, whilst also forming a good proportion of the discussions that happen outside of tutorials via email. The blogs, through their accessibility, have become a good format for suggestions and compliments from tutors, which has transformed the studio culture by enabling deeper discussions to take place in terms of the students' design processes in between the formal timetabled sessions. As previously discussed, the current situation has not always been the case and "pre-blog", in 2012, I was facing problems of poor attendance in feeder modules, a weaker engagement from international students due to severe language barriers and a general poor understanding by students of the value of contributing subjects such as architectural history and theory.

My first encounter with blogging technology was an attempt to highlight better connections to supporting topics and their relationship to the "design studio" module. Initially asking the students to "blog" their lecture notes, I intended to enable the content of these modules to become more accessible digitally as opposed to hand-written notes stashed in the back of a folder, and to enable the material to become "portable" so it could be discussed more easily. Together with using similar precedent studies, sites and other material, the aspiration was that the cohort would begin to realize that studio, although a key component of the architecture course, was not the only module of relevance to their training to become an architect. The outcome of using the blogs in this way evidenced a clear shift in attitudes by the students and to my complete surprise, the students not only began recording their their work for history and theory lectures on their blogs - but all work

- for all modules. Happy accident number one had occurred. One student commented “by having all my work in one place, I was able to see the relationship between my modules more easily”. Another said “I often look at other students’ blogs and learn from them. I feel if I load up my work to the blogs I know others will be looking at it. I feel it is important to keep it looking good.”

Blogs assist the students to collate their thoughts and work for the course with a holistic mind as opposed to a secular one. They extend the tradition of private critique occurring within the interior of the studio walls and put the student work into a larger context enabling self-reflection and a more rounded consideration of their course. These first steps in creating a blogging culture certainly had an impact on the students’ attitude and approach to displaying their work. An improved level of pride developed within the student for their work and their online display of themselves. A format that can be seen by friends, tutors, peers, family and the general public, the students began to recognize the importance of representing themselves online and through online communication and presentation, the group progressed further in self-evaluation and became critical of their own personal learning path.

During my first year of blogging I found myself faced with several advantages of the technology that I had not anticipated. A lack of confidence when presenting verbally, a poor ability to document development work and a nervousness when declaring sketch work in projects, first year students are a sensitive group to encounter. Making discoveries, learning new skills whilst at the same time attempting to establish who they are within the context of their school and their studio, their journey through architectural education can be a challenging time in more ways than one. Using the blogs as a tool to record and evidence each step of the design development process and therefore their learning journey, I wanted to help develop the students’ confidence by encouraging them to connect with what they produced, and reflect upon their improvements as they progress through the year. Often we encourage students to look ahead towards the cohorts of second, third year and even Masters level work. However, sometimes it can be more useful to appraise work gone by in previous projects and make comparisons to the work currently being produced. Learning for a first year student is fast-paced and to keep up, new skills in communication and representation must be acquired relatively quickly if they are to present their ideas successfully. Through the use of blogging, the students were able to “carry” around previous projects and work with them and have it to hand to call upon when necessary. A frequent practice in studio became about “reflection” and looking back at earlier projects in the critique of a current project, enabling tutors to highlight to the students the new skills that they have learned and improvements made. The benefit of the blogs is that the students can also do this themselves at any point. The blogs provide a fantastic test for the logic of one’s process, and provide tutors with the ability to view the “whole” student, not simply one project in moderation and marking. Blogs can therefore also be an encouraging tool for tutors to reflect upon student progress quickly and continuously. As opposed to waiting until the end of term/year portfolio review, one has complete access to all student projects and modules at any one time.

It was also clear that using blogs to help students when verbally presenting their work provided a structured, chronological and graphically pleasing record for the students to use as a prompt in design reviews. Computer screens or laptops were provided in the design reviews for students who chose to present from their blogs, and blog links were recorded to enable tutors to refer back to the development work for marking. This noticeable shift in studio culture meant that it became much more comfortable for those students

who struggled with confidence when speaking in front of an audience, for international students needing to overcome the language barrier and in general to assist all students in learning the skills necessary to present their work in an orderly, chronological format to better explain their project from concept to the final proposal. For the tutors, the blogs revealed the attempts to develop design ideas at various stages of the design process and for one to understand the learning path taken by the student, pushing beyond the limitations of a strict portfolio, the blogs have become a useful aid to better communicating with the student about where they can make improvements and which ideas [throughout the whole design process] would have been useful to work up further.

As an aid for storing ideas and saving work, the blogs have also become a favoured and reliable tool to refer back to should work become lost. Students commented, *“as a tool for reducing printing costs the blogs are great! I can take photos of my models, save images of my precedent studies and scan my sketches all in one place without having to print them off for tutorials. This has saved me lots of money!”*.

FOR FEEDBACK AND ENGAGEMENT

Being able to provide formative feedback on the blogs at any point in between project submissions, tutorials and timetabled contact time with students has enabled myself and the other tutors with the opportunity to provide interim guidance. This guidance would not have been possible before the blogs became integrated into the studio due to a lack of time and lack of studio space for additional tutorials. For beginning design students embarking on a new subject and new course is daunting and as a result this hesitancy to make design moved can hinder learning. Early intervention when a student begins to waver on their design decisions, lose confidence or even become disengaged has proven to be very helpful when attempting to maintain good retention. This type of feedback has been called “Advice for Action” (Whitlock, 2010). Solid data and student feedback collated over a period of 4 years at NTU has suggested solid evidence that blogs can be one way of aiding students during their first years of learning, reducing the fear and consequently improving progression. Maintaining a higher level of inner confidence with the students has also helped to improve attendance. One student commented *“I like being able to send my work in development to my tutor. On my blog I can upload my sketches, thoughts and scribbles and my tutor can see it in context. Support between tutorials has helped me stay on track when I have been stuck. It helps me catch up”*.

Not only does the drawing together of information into one place become beneficial from the point of view of feedback, but it also aids students to visualize their growth of knowledge, understanding, abilities, motives and demonstrations of learning in their design development, whilst at the same time enabling an easier transfer of information from and to contributing modules. This saves students time and as previously explained, encourages positive reflection. From the beginning of my blogging initiative, I started to notice a drop in students falling behind with their work or reaching the end of project review with nothing. Almost all of the time, some useful work can be found on the blogs to assist the student in presenting their work in a way which is useful to the critic.

Although I cannot finitely link an improvement in student attendance completely to the introduction of studio blogs, I can evidence that some students who missed sessions were able to be reintegrated into studio more quickly by tutors being able to communicate with them via the blogs when absent. Students missing studio sessions were able to communicate with me outside of the timetable, which meant I was able to assist them to catch up and feel more able to return to the programme following an absence.

TO LIST ADDITIONAL “HAPPY ACCIDENTS” THAT OCCURRED IN THE INITIAL YEARS WHEN INTRODUCING BLOG TECHNOLOGY INTO THE STUDIO:

1. Blogs provided students with the ability to capture their ideas in a range of different, non-standard formats, eg: video and photography, screen grabs of CAD in the process of construction, and store them digitally ready for review and presentation at any stage of the design process. See graphical examples as part of the appendix.
2. The blogs reduced time wasted for students when working independently on ideas away from the studio and made scheduled tutorial time more productive.
3. The blogs presented an online persona for the student further developing a confidence that some did not have in the studio and one that could then be nurtured by the tutor.
4. The blogs supported student learning through play when undertaking tasks, which sometimes can be very formal. Incorporating their reflections, thoughts and feelings about the project, the cohort began to engage in more active discourse with both their tutor and peers.
5. Blogs encouraged more peer learning and collaborative practice opening up studio projects to a wide range of possibilities for group work and sharing practice.
6. The blogs created a space for facilitating a more expansive reflective process and continuous review of previous projects, which once “live” can be made continuously accessible (as opposed to in sketchbooks tucked away at home), the blogs encouraged students to become more aware of their own learning and promote critical evaluation of individual progression.
7. Reduced the amount of work “lost”. Models were captured in process and sketches were recorded. The development process involved in their designs had been stored and became visible.

Reevaluating the use of blogs each year has seen the use of this technology grow and become more integrated not just in studio practice, but in other modules to help students learn how to reference essays correctly, for correct use of precedents and for creating a full academic portfolio to send to potential employers. In the past year I have also begun to use the blogs to communicate with new applicants to provide them with a snapshot to the course that they otherwise would not have had. Being able to tune into a “live feed” of the studio and other modules has provided potential students with the ability to really pose the question “is this course for me?”. A more honest and open representation of what learning architecture is about facilitates a better chance of the right student being placed on the right course. A better presentation of the course content has also been made to international students and those who cannot attend open days or applicant days. Using some of the student blogs, which provide an excellent representation of the modules within the programme at my school, has enabled me to communicate better not only the academic content of modules but the enthusiasm and activity that happens in the delivery. A flavour that you cannot attain through conventional marketing via a prospectus. I have used the student blogs to send to newly registered applicants to help them prepare for their arrival to the university and whilst this has put pressure on myself to have to reinvent projects each year, I feel this can only be a positive pressure to ensure my studio is consistently new and refreshing. Happy accidents that have come about from using the blogs in this way include prospective students that have attended applicant days emailing me their school

work via blogs they have been encouraged to create, a domino effect happening within my school with colleagues now taking up the use of blogs within their programmes having recognized the benefits, not to mention the many collaborations both locally and globally that have been made possible by the ease of sharing material online.

In addition to the potentials within studio discussed above, as referenced here we also began to consider how social media might also be used collaboratively apart from the tutor/student relationship. To continue the earlier discoveries, I wanted to look deeper into one or two of the benefits uncovered by previous research. Could the blog, or other social media outlets, be used as a beneficial critique tool on a larger scale? The process could expose students to perspectives outside of their own university or country, to link at a 1:1 level with willing educators and professionals in other places with no cost to the universities, and gives the individual critic more time to engage with the work.

Having previously begun using the Weebly model introduced by Victoria, the idea of using a proprietary Facebook group with selective membership was an area of exploration as well. This began through a sponsored design studio run in the summer of 2015 at Marywood University with the Dallas Texas based furniture company Groovystuff. Due to the nature of the studio and its relation to a design manufacturer, a more private setting was desired. Using the Facebook group with the studio instructor and company president as trusted administrators allowed for the invitation of select critics without the potential dissemination of design material to other manufacturers. The 'security' of the site resulted in candid, informal discussions and critique from all involved. The students posted their work, from inspiration and sketches to models and final product boards, on a weekly basis. This would garner feedback from the Groovystuff team in Texas as well as from myself. As a collaborative tool from afar, postings could be accessed at any time of day and commented on/replied to many times. In this way, each iteration or thought could be presented, documented, and developed in a timely fashion. The private nature of the group allowed for informal as well as formal critique and response from the students.

In the autumn of 2015 I chose to build on the experience from the summer and engage in a project with my second year design studio at Marywood University in order to explore other avenues of social media critique for comparison. The second year 'Fall' within our sequence is a shared studio between Architecture and Interior Architecture students and acts as a bridge between the abstract quality of first year and the more concrete reality of upper levels. This project involved an introduction to site conditions as well as basic programmatical issues along with continuing exploration of graphic communication. None of the students had been a part of the summer group, and so did not have preconceptions going into the process of using the blog as an online critique tool. The students were in the final stages of a half-term project, and we paired them with critics from Europe that we felt would work with the studio level and critique method. Critics came from academia as well as from the profession and were located throughout England with one coming from Austria. Being a new format for both the critic and student, we allowed for a certain amount of openness to the process to be able to assess the tendencies of all parties involved and gauge how to modify the methodology. The online presentation model requires and encourages the student to address their work in a different manner, without relying on being able to talk around an issue. The student needed to explain the details that they feel are important to a greater extent, to ensure that the point is seen rather than relying on it being discovered. Through this the students must consider how they best accomplish this through a balance of image and text.

The critics were given a cursory introduction to the project and were able to dictate how they delivered their critique, whether directly as commentary on the blogs or as separate documents, and were given a one week timeframe in which to respond to the blogs. While the prospect of a virtual 1:1 critique does allow for more focused time as well as more flexible time in which a critic can engage with material, rather than sitting in front of 20 students over a 5 hour period, it does allow for the possibility of time getting away. I found that the timeframe worked well for some while it, coupled with the process being open to interpretation for the initial trial, resulted in several of the critics responding at the one week point, or much later.

From the initial blog-based critique model we have been able to process information on the potentials and pitfalls of the process from both the side of the critic, Victoria, and of the faculty, Stephen. The students need to be urged to explore how best to communicate their ideas without interacting with an audience. The Marywood students have been working with the blog as a documentation tool for less than a year, and for many of these students it was their initial experience of the medium. With continued use of the format for documentation, the students will become more adept at communication without direct interaction and will be able to better represent themselves in critique. As the faculty involved, there is need to develop a rubric to alleviate the pressure on the invited critics. We found some critics were uncomfortable posting publicly and returned feedback via email whilst others typed feedback direct to the blogs.

The experiment posed further questions: What is the potential for social media-based critique, whether formal or informal, and will it replace the in-person dialogue between critic and presenter? The potential is limitless as a means of connecting students with peers, academics, and professionals outside of the scope of their surroundings. As far as replacing physical interaction, we say no; augment the experience, yes. The contact time we spend with our students is at such a level that they are prone to tune out at a certain saturation, this would be a point that another opinion (even if it is saying the exact same things) might be the one heard. In the society in which we live, often people strive for more 'likes' on a post from people that they do not know than for one positive comment from the person sitting next to them. Exposing the student to a new body of knowledge or way of working can only help to push them forward in their own methodology. In addition to this, we plan to further explore additional linkages that could be made beyond peer learning in studio or indeed the school or country, but also to investigate peer learning between students from various universities and to elevate the consciousness of social media to work towards a greater use. How can social media be used not only to show students what has been done, but to allow them to see what their peers are doing not just in the final outcome, but in the iterative steps of the process to allow for questioning each other to develop their personal language.

FURTHER DEVELOPMENT WORKING WITH BLOGS

Through undertaking these exercises we have uncovered a wide range of additional benefits from using blogs. The audience has heard a snapshot of just some of the discoveries and investigations we have been making.

We have since expanded my strategy to begin to address how the resource can be more widely used within my programme and further afield. Already members of different faculties at Birmingham City University have begun to see the benefits of blogs used in this way and have begun to introduce it to their own courses. This also includes the workshops and HR and I am keen to record the outcomes of all different routes the blogs may define.

Over the last two years in the UK, alongside Stephen working in the USA we have been making blogs accessible to new applicants in order to showcase the activities that are happening in studio to more accurately portray what the architecture course involves. This honesty and transparency for students is, we believe, critical in assisting them to make an informed choice in regard to their place of study. Incorporating the blogs into open day material, applicant days and other marketing material gives students a live “snapshot” of studio life. In my studio I have also witnessed students sharing their blogs with families and friends outside of the course, which has gone some way to bridging the gap between students and their circles at home. I have helped students build up their own digital CVs and become better prepared for selling their work prior to an interview. I have also expanded the use of blogs beyond Year 1 Undergraduate level to implement my e-learning strategy with a group in Year 2 in technology modules, at Masters level with dissertation students and in collaborative projects, which have involved architecture students working with Fashion design. Each one of these initiatives have been made possible through the use of blogs and social media. We look forward to exploring further possibilities with this initiative, and witnessing and being part of more “happy accidents” in the future.

Learning environments in design studio culture: exploring the student experience

Julian Williams

University of Westminster, UK

Central to any architecture course are the activities of the 'design studio'. The term embraces a culture of formal and informal activities focussed on project-based learning. A design studio also includes the physical spaces of the studio and possibly other work and study spaces, bound together by a language and culture of expectations, practices and values.

The research discussed here was undertaken in a UK school of architecture with a typical studio arrangement; demarcated spaces for years or groups (ateliers, studios or units), in a larger open plan environment. Students negotiate within the group for the use of the shared workspace, which also operates as a teaching space.

Learning in design studio cultures has been theorized as a signature pedagogy emulating professional practice models, as a community of practice and as a form of problem-based learning (Shulman, 2005) (Lave and Wenger, 1991, Wenger, 1998). These concepts are reflected in emerging models like the London School of Architecture (www.the-lsa.org/network), through dispensing with dedicated studio provision; aiming to relocate existing signature 'pedagogy' elements (the crit, the 1:1 tutorial), and relying on professional practice communities to nurture students' learning. But what of existing architecture schools with their studios and workshops? What is the value of informal studio spaces as an umbrella setting for teaching and as a creative space for student learning? Given that the studio is a major investment for Higher Education Institutions, this research asks what role traditional environments like the studio have in supporting design studio culture beyond actual teaching sessions?

RESEARCH METHODS AND APPROACH

Semi-structured interviews with final year undergraduate students of architecture formed the basis of the study using an interpretivist approach informed by Actor-network theory (Callon, 1986, Latour, 1987, Fenwick and Edwards, 2010, Fenwick and Edwards, 2012). The interview process was supported by visual elicitation techniques to encourage rich responses.

Five themes emerged from the analysis. The overwhelming focus of work was portfolio production, but was mediated, and often impeded by uncertainties of tools, equipment and other necessary things. Students articulated their involvement in studio culture through the terms of a notional community, with a social milieu that supported peripheral collaborative and social activities

that surround formal teaching, with decisions about where to work being informed by identity and sense of place.

Here I shall be discussing the notional community the students formed in the context of community of practice models and, drawing on Bourdieu's model of practice, considering informal use of studio spaces as a social dimension that enables students to develop their habitus.

A COMMUNITY OF PRACTICE?

Communities of practice theory challenges the idea that learning happens through cognitive mechanisms (as put forward by Schön). Lave and Wenger's model has obvious resonances with the activities of the design studio, both as a result of the problem-based learning approach and the student centred organisation of spaces and facilities (Lave and Wenger, 1991, Hughes et al., 2013); Examining the student community's network against the accepted characteristics of a community of practice as defined by Barab and Duffy (Barab and Duffy, 2012) indicated that it held cultural and historical heritage, shared meanings, goals and practices, but that these were not inherited from older community members' experiences. Tutors were seen as having a responsibility in galvanising the students rather than 'old timer' members. Student A described a Friday after studio:

"...we're probably going to go for a pint or something. The tutors as well. Like it's nice because most of the times they're trying to join us as well...because like the tutor is the one who tries to bring everybody together. It's everybody's connection is in the middle so it's the tutor." (Student A)

The degree of identification with the community varied. Student M, who worked at home, was clearly sensitive to his peripheral place:

"Yes, I think in general I feel part of it if that's what you mean? I feel part of it and I think they perceive me as well as part of it. They don't think, 'Oh this is the guy that never comes' or anything like that. No I don't think they have that feeling." (Student M)

This understanding was at odds with other views, and the experiences of Student A, an ardent studio participant who used multiple means to ensure her presence in the community:

"our whole life basically has to do with us coming in every day and or even if I don't come in it's like all the time I mean...we have like a group you know on WhatsApp we have a group conversation so we're like texting between us...the studio people all the time like where are you what you're doing..." (Student A)

The social development of community emerged from working together on similar tasks and on stressing cherished differences between themselves and other (non-architecture) students. This community's boundaries were tightly drawn around studio culture, sustained through a symbolic dimension in the form of values, codes and common experiences (Cohen, 2013).

Students talked about a currency of ideas and thinking, blurring boundaries between themselves and the community. They were prepared to share knowledge, within limits. Student L described requests on Facebook from studio non-participants:

"They are generally the ones asking, yes. There seems to be often a lack of reciprocation. You know, you will provide photos for everyone and maps for everyone because you have done the work, which can sometimes be annoying. But you don't want to come across as an asshole." (Student L)

The characteristics of this community reflected many aspects of Cohen's analysis: The students talked using a shared identity and repertoire of actions, and could describe their social boundaries (Cohen, 2013). This analysis concurs with Morton and Shreeve in so far as finding that a community of practice model was not reflected in the studio environment, and furthermore not outside it either, but did not conclude that this was the result of independently focussed practices (Morton, 2012, Shreeve, 2007). Students did not operate as isolated practitioners - even the most peripherally engaged students made efforts to keep up tenuous membership. Contrary to Lave and Wenger, students' identities were not forged through community participation: students learned to belong, but did not behave as newcomers; they brought background experience and expectations, showed prior familiarity with design studio ways and were quick to develop their new identities, reflecting popular representations of design studio culture in the media (Frederick, 2007).

Bourdieu's theory of practice has relevance through the way it relates individually acquired ways of working to social contexts, where habitus involves the externalisation through the social realm of previously internalised habits and practices. The research suggested that the community acted as a field, in which the student could develop their habitus, acquiring social capital (being contactable, being the centre of things, driving the social milieu) and cultural capital (practicing-knowledge). Students with greater experience were not seen as 'old-timers' by others, and were quite guarded about sharing their knowledge: they did not reflect community of practice roles in this sense. Their practicing knowledge and habitus offered 'distinction' that was not freely given away.

The research echoed Webster's point that learning, in the form of making sense of disciplinary knowledge, was happening outside of formal teaching (Webster, 2008) and in a realm that included, but was not limited to, the studio spaces. The social milieu of the community was a space for reflection along the lines of talking through, making sense and 'playing the field' (Bourdieu and Nice, 1977).

BEING IN PLACE/OUT OF PLACE

Students worked in the studio and workshops, the library and at home, in their bedrooms, living rooms and kitchens. All were restrictive in some way or other, but did not appear to determine outright their working patterns. The students held in tension two often conflicting desires: to create an equipped space of creative potential free from practical and time constraints, and the need to work or simply 'be' in the presence of others. For example, although the studio was seen a messy workspace and suitable for modelling and constructing, students talked about setting up at home, in their living rooms and kitchens: They would either have a small home studio permanently set up, or temporarily convert shared or family spaces.

I have used the envelope terms of being 'in place' and 'out of place' to characterise the uncertainty of studio as a place of work and the importance of social milieu in shaping this. Students described setting up workspaces at home where they would feel 'in place' and ready to work, in a supportive environment and with the right things to hand. For the most part this involved temporary setups, for weekend and night-time to support work done in the studio:

“Previously I used to just work on the living room table, but then you get slightly distracted...You need to be set up properly...You need to have all of these things, just to make your life easier, to ease into the work.” (Student R)

“At home I don’t really do work on my laptop... I’m probably on my drawing board because I don’t bring my drawing board into the studio so I’m probably drawing at home or model making. I’ll just take over the living room, just have it all over the floor...” (Student S)

Student A described turning her shared living room into a plaster-modelling workshop: a time-unlimited space for back and forth working. Students used social media, like WhatsApp, to support being in place at home and working on their own:

“Then at home, if somebody was not doing okay, then we would just call up, talk about it...when it comes to not being able to figure out a particular thing that’s when the phone comes out.” (Student R)

For other students, the studio itself was the space where they felt more ‘in place’, with both social activities around sharing work in progress and mutual support, and material activities of getting on with work.

“I mean it is not so much about them seeing that you are doing the work because they see that anyway through your work, but it is more about staying there...and there are always people who ask for help, so that is reason we stay now. Sometimes we stay until like 11:00 when it closes.” (Student L)

The studio differentiated itself as a place to work alongside with peers with face-to-face. The practical concerns like more working space and facilities were secondary to these social opportunities. Being in place in the studio thus had two connected dimensions - a social dimension, and a material practicing dimension in the context of the social. The material practising dimension was conditional upon having the right materials, equipment, space and the freedom to make a mess. The social dimension was supported through social media, negotiating and organising for a collective presence.

IN THE STUDIO – OUT OF PLACE

The studio was not an intrinsically conducive place to be. Events or other actions could quickly lead to students feeling ‘out of place’ and therefore stymied in their plans to work. Shortcomings in getting space in which to coalesce was a recurrent concern:

“... I’m sure that’s our unit space so that’s Unit G’s unit space, but sometimes...we’ll come in and they’ve taken over the whole space...so they’ve poured out into ours, they’ve spilled over into our unit space. Then it’s just like where are we meant to work? If you’re all in and they’ve got their massive A1s... then they look at you like why are you here? This is our unit space where we’re meant to work. I’m not sure if that’s actually their designated day but then they have their own unit space so I’m not too sure. ... we have to go and find somewhere random, maybe downstairs if that’s empty to work...it felt weird being in that space.” (Student S)

Problems with the material dimension of working, from forgetting to bring things to the sense that the studio was not a practically amenable place, meant that some students worked exclusively at home. Student M described his perfected set-up, which he supplemented with discrete and episodic visits to the architecture studio. Beyond this interaction, he felt out of place in the studio and drawn back to his home set-up.

"Well I tend not to work in here most of the time, because I think it's a bit messy, it's difficult to get yourself space...I don't think you can do it here the same way as I do it. I don't know if it's the best way, but it works for me.... I can't see how that could relate in here, you've been to have a look at your digital model and you have to go to the model room, to the computer room and then go back to what you were doing in the workshop. Probably someone has stolen your place when you went to check something that you want to change on your model." (Student M)

With the exception of permanent home set-ups, provision for storing things was ad hoc. The studio imposed an almost itinerant work-style:

"Quite a few people have their own [locker] ...or we have a little space where our models are, sometimes I just put my stuff behind there, hidden behind the models or something so if I need to get it I can come in the next day and just take it. Or our portfolios are all stashed at the bottom ...or I just put it in someone else's locker and then they'll lock it up for me. Nothing important, it's just usually work. I won't leave my laptop or anything. I'll just leave my sheets of work or a roll of paper that I've used or my model if I don't want to carry it home and then bring it back." (Student S)

So the qualities of being in-place came down to the degree to which they could invite and hold social and working practices. Variable occupation, negotiate through both prior practice and use of social media reflected the studio's role as a social milieu:

"...10:00 in the morning onwards we are supposed to come in... 10:00 on the dot no one is there, myself included...People filter in through the day. Generally, you will get a certain group of people who will be there from like 11:00 or 11:30 onwards to 7:00 at night. Then you will get a second group of people who will come in for their tutorial but then leave again. There are almost two separate groups. One is a permanent, they know they have to stay there, they know they have to work and that it is easier to work there, and they do that. Then there is another group that just filter in and filter out according to when their tutorial is." (Student L)

Students struggled to confer onto the space enduring markers of 'in-placeness'. Student S, described her first experiences of studio work in 1st year:

"It changed. Sometimes it would be at the far end of the room. It depended as well how many – because our work was individual but we had like a group of us to one tutor. If most of the group was in, we got a bigger table. I guess if another group, there weren't too many people; there was less of them so they made a smaller amount of space, kind of thing. It changed. If everyone was in, then it got a little bit ... so sometimes we'd have to use a little bit of the space next door." (Student S)

Working in the studio required the planning of set-ups and the organisation of things; It was an uncertain space when compared with converted living room tables and bedroom floor.

However, in the social dimension, the studio acted strongly in enrolling the community:

"we have like a group you know on WhatsApp like we have a group, like conversations so we're like texting between us like the studio people all the time like where are you, what you're doing... what time you're going..." (Student A)

The 'studio people' would co-ordinate their studio presence, agreeing when to go into

studio, converging at the same moment.

Using studio facilities was seen as an investment, requiring effort and planning, but one that was rewarding. They could describe how the design studio should work in theory, but negotiated their own, often-vicarious patterns of attendance and participation. One student advantageously compared his own investment in studio working with others who were marginal participants:

“They always look unhappy when they do finally arrive. It is because... they are not enjoying it because they are not getting fully into it. It just becomes something they don’t want to do but have to do in a sense which kind of defeats the point of being here...” (Student L)

When you are all here you can bounce ideas off each other and if you don’t know how to do something someone else might. Then you can, you learn a lot more if you are in the studio working with other people rather than being at home. (Student L)

PLACE AS FIELD

Bourdieu’s model of habitus, field and capital offers further a useful framework for considering this condition. The social milieu of the studio provides a scene for the practice and display of ‘practicing’. It is a kind of field where this *practicing-capital* can be accumulated and displayed. It is a property of the social milieu rather than the space, so working or practicing in the company of others (in space and through social media) becomes a more valued aspect of studio than simply space or facilities.

This practicing-capital is linked with the acquisition of a habitus of studio culture, the transformation of physical practices or habits into social dispositions. The studio milieu had value even to the isolated home working student: Student M described his need to come in and see what other students were doing, and with much effort to work for short periods in the studio space, as a kind of gesture and display.

Being in place in the studio allowed opportunities to practice externalising hitherto internalised knowledge. And what is important here is that this externalisation needs to happen in a social context for social capital to be acquired. Student L described students who didn’t appear in studio as disengaged, as having nothing that he would want, no social capital.

In the days before a crit, Student L noted these students’ increased presence in the studio. This can be read as the student’s need to explore the field, trying to acquire more social capital.

Being in place in the studio (as opposed to being in place at home) required negotiation and had costs, but despite this, the students were prepared to do it. The social milieu allowed them to pursue practicing-capital (in Bourdieu’s terms, to be better at doing, more efficient); a symbolic capital alongside the social capital and cultural capital (know-how).

The teaching in the studio offered an extension to this field, giving the students the chance to accumulate more (and more distinguished) capital through events like the crit.

THINGS AND EVENTS IN PLACE

Things acted as gatekeepers to the design studio: having them signified belonging (I have these things, I am an architecture student) and using them signified doing, practicing. Whilst a lot of this went on in private, the social dimension was for all the students interviewed, an indispensable element. Even for Student M, the committed homeworker, a stint in the studio was a chance to practice in a social milieu. So having and using things were not just practical and material issues, they had a material and social dimension that was most clearly evident in the studio setting itself. Students who used the studio to work in could trade their know-how; display their things, techniques and working processes.

Drawing from Bourdieu's conception of practice, this activity can be read as a mechanism for externalising by practicing modes of doing. Students who worked in the social milieu of the studio were "getting a feel for the game" by exploring the limit or boundaries of the field of studio culture, believing in it, and its "sensible" practices (Fuller et al., 2005).

The crits came as apogee moments in their field. For the confident students, it was an opportunity for them to have their work recognised by students, staff and external 'professional' members. This was not just about the recognition of the value of their work, it was, through the inter-subjective nature of the crit, a process of participants giving and accumulating capital from each other. This capital took the form of knowledge, cultural or 'practicing' capital, and social capital. Student L described his skill in leading his crit audience, whilst Student S had hers at the end of the day with only one friend to watch [after it had finished it was late and she said the tutors left quickly with the guests].

DEGREES OF ENGAGEMENT

Around the formal teaching like the crit and the tutorial, there were meetings on social media, informal agreements about staying and waiting for friends to have had their crit, and social get-togethers like going to pub. These were student initiated, informal and ad hoc:

"It is a reflection on the day. Generally, we just point out what everyone has done really well and just try and shy away from the negatives. We let the alcohol do that. But yes, it is a mixture of commending each other and slagging off the tutors, like saying what you thought. If you think they are wrong on something, then you discuss it at that point." (L)

Attendance at these events was limited. They were not embraced by all members of the group, and although the students wanted their tutors to come along, there was some awkwardness about how the community could embrace them. Students struggled to recognise others who were either peripheral or non-participants even when this description fitted their own pattern. Student F described the exhaustion of working up to the crit, of staying to listen to his friends present and then immediately going home. Student M was more open about his responses to the crit:

"I normally try to stay if I see that I'm hearing interesting things, I stay until I get bored and then I go..." (Student M)

CONCLUSIONS

The study indicated that design studio culture involved a network of elements that supported learning; much of it situated outside formal structured teaching. The analysis used Bourdieu's theory of practice to further the consideration of how the students developed their practice. The process of internalising and embodying studio habits and learning studio habitus took place mainly outside of structured teaching, so peripheral students therefore lost out in their opportunities to develop habitus: Student M didn't see

any point in sticking around after his tutorial as he knew he wouldn't see the tutor again for the rest of the day, whilst L got that studio culture was a kind field for testing out where he was at, and saw non-attenders as outsiders to this.

The research highlighted some very straightforward practical problems to do with the need for things, inhibiting studio use and as a consequence reducing involvement in the social milieu of peripherally engaged students. Such students also drew back from the pressures of performance in the social setting. This suggests that there are opportunities to advance design studio culture by broadening participation in the notional community, challenging marginal participants who stand at the boundary of the community avoid engaging in 'the game'. The tutor has a possible role in stimulating and extending the notional community even though they cannot themselves be insider participants. They can encourage reflective talk by recognising that participation in community is not just a support network, but site of learning through practicing in a social arena.

REFERENCES

- Bourdieu, P. & Nice, R. 1977. *Outline of a Theory of Practice*, Cambridge University Press.
- Callon, M. 1986. Some elements of a sociology of translation: domestication of the scallops and the fishermen of St. Brieuc Bay. *Power, action, and belief: A new sociology of knowledge*, 32, 196-223.
- Cohen, A. P. 2013. *Symbolic Construction of Community*, Taylor & Francis.
- Fenwick, T. & Edwards, R. 2010. *Actor-network theory in education*, Routledge.
- Fenwick, T. & Edwards, R. 2012. *Researching education through actor-network theory*, John Wiley & Sons.
- Frederick, M. 2007. *One Hundred One Things I Learned in Architecture School*, MIT Press.
- Fuller, A., Hodkinson, H., Hodkinson, P. & Unwin, L. 2005. Learning as peripheral participation in communities of practice: a reassessment of key concepts in workplace learning. *British Educational Research Journal*, 31, 49-68.
- [HTTP://WWW.THE-LSA.ORG/NETWORK](http://www.the-lsa.org/network). [Accessed 26/08/15 2015].
- Hughes, J., Jewson, N. & Unwin, L. 2013. *Communities of Practice: Critical Perspectives*, Taylor & Francis.
- Latour, B. 1987. *Science in action: How to follow scientists and engineers through society*, Harvard university press.
- Lave, J. & Wenger, E. 1991. *Situated learning : legitimate peripheral participation*, Cambridge, Cambridge University Press.
- Morton, J. 2012. Communities of practice in higher education: A challenge from the discipline of architecture. *Linguistics and Education*, 23, 100-111.
- Shreeve, A. 2007. Learning development and study support an embedded approach through communities of practice. *Art, Design & Communication in Higher Education*, 6, 11-25.
- Shulmann, L. S. 2005. Signature pedagogies in the professions. *Daedalus*, 134, pp. 52-59.
- Webster, H. 2008. Architectural Education after Schön: Cracks, Blurs, Boundaries and Beyond. *Journal for Education in the Built Environment* [Online], 3. Available: http://www-new1.heacademy.ac.uk/assets/cebe/documents/resources/journals/jebe/vol_3_issue_2_architectual_education_after_schon.pdf [Accessed 25 December 2012].
- Wenger, E. 1998. *Communities of Practice: Learning, Meaning, and Identity*, Cambridge University Press.

The studio as site: Exploring the positionality of the designer in the creative process

Matt Ozga-Lawn & James A. Craig

Newcastle University, UK

INTRODUCTION

There is a well-established critical discourse surrounding the experience of architectural imagery. Robin Evans, as a key example, tells us of the performative qualities of our engagement with representation, and of how in this engagement we think spaces into architectural imagery and objects in a “generative act” (Evans, 2000) that might be itself considered as the production of a spatial event. This discourse demonstrates a conceptualisation of architectural (and art) criticism that incorporates and embeds the observer and representation into a generative dialogue, in which architecture is understood as a shifting and interpretative meeting of the coding and phenomena of the image with the subjective positioning of the observer. This paper will, on the one hand, engage with this understanding of architecture as, in-effect, produced through its interpretation, and will look at the potential this unlocks in the consideration of architectural images and objects. However, while this concept has been furthered and utilised by many theorists and designers since Evans’ writing in the 1980s, there are aspects of our engagement with architectural representation that have often been over-looked or are under-theorised. One such aspect, and one that this paper is concerned with, is the nature of our engagement with architectural representation during the process of its production. We view this as particularly relevant given the radical changes in the production of architectural projects since the 1980s, and in this paper we discuss projects – from our practice and pedagogical approach – that focus on the nature of our engagement with them during their production.

A second and vital consideration for the projects in this paper is with the nature of the space in which we engage representation – the space in which both observer and representational artefact are contained and the interpretative performance described above takes place. We begin by attempting a definition of the qualities of this space, which we refer to as the studio. This complex space is one in which immediate material conditions are merged with the figurative and abstracted spaces contained within and – significantly – **between** representations, and between representations and ourselves, and it is a space that is also engaged with (often simultaneously with the representational artefacts it contains) through its observation and interpretation.

STASUS, our design-research practice embedded within the Architecture Department at Newcastle University, concerns itself with the nature of this

space and how we act within it in the production and interpretation of architectural works. Through our projects and our pedagogical approach, we examine the position of the observer in relation to the architectural project and the space that is generated around the experience of its engagement. We view the studio as the site of the design process: a site which embeds and enhances projects and gathers and transforms their ostensible and distant sites and critical contexts. Newcastle University's MArch programme is centred on a diverse range of research-led studios, within which we have led a range of thematic explorations based on a critical interpretation of the nature of this studio space and our engagement with it. We are particularly concerned with two modes of production: of the architectural project as a continuous dialogue between representational artefacts and their observation within the framework of the studio; and of the production of space and meaning involved in the generative act of their interpretation. The studio in this mode of critical study is both the space of design production, and a placeholder (to take the compound word literally) for the complex intertwining of spaces, meaning and potentialities that this involves.

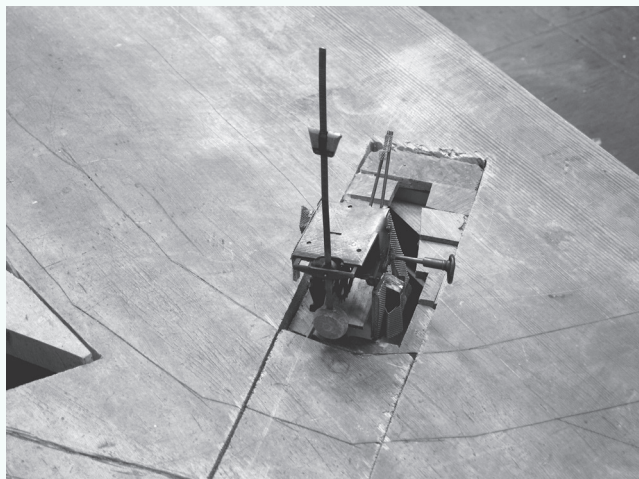
DEFINING THE STUDIO

The studio is something of an unknown in architectural discourse. It is a “*key site of architectural production, yet it is not often thematised or reflected on in any rigorous way*” (STASUS, 2012). As a site of production, it contains and holds the architectural project in process and completion, yet, unusually for a discipline concerned with the production and nature of space, it is not a clearly defined space in itself. It is the space in which design comes about, and through which decisions are made, a “*practical assemblage, a mechanism of statements and visibilities.*” (Deleuze, 1988). In the studio, the observer moves from an outside position to a necessarily integral part of the dialogue that constitutes a design process. Visual relationships, often accidental, are created between elements of projects (and between separate projects) that may hold little in common, but which are united by their presence in this space and the observer's engagement with them. Something arguably unique to the discipline is an intensification of both the need and pleasure in reading between disparate representations, so that, for example, the plan and the section can be read together to generate a space with the engaged imagination:

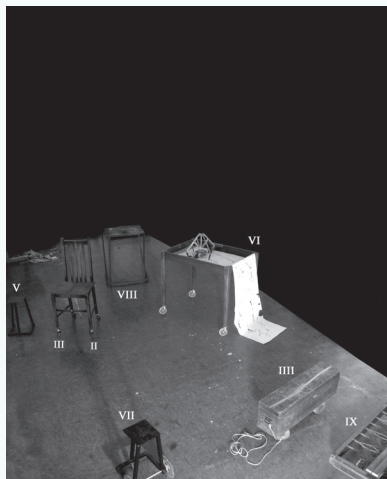
“[this] combination of information from several different drawings – for instance the plan in combination to the section... [is] a suspension of pleasure that produces desire... leading to a slow blossoming of the design structure in the mind.” (Haralambidou, 2013).

This is the basis of the reading of architectural representation, manifested in project reviews in architectural education (informally referred to as crits), but it is also the continuous relationship established between designer and the representational modes employed in the studio; a reciprocal navigation and negotiation of the space(s) between representations, both contrived and accidental. In our practice and pedagogy, we attempt to maintain a conscious elevation of the processes by which designs come about, and the suspended pleasure of allowing room for, and expanding, the space between the disparate elements of these processes, by drawing attention to the nature of this space, and holding it as the site of architectural design, as opposed to the hidden mechanism behind it.

“The studio thus appears as a kind of space of transmission, a space through which something has to be sent, which would suggest that to admit it into the architectural project, and to welcome its effects, would be something akin to welcoming interference on a telephone line.” (STASUS, 2012).



▲ Figure 1 The Metronome



▲ Figure 2 The Collection

To allow this interference is to become aware not only of the relationships between the constituent elements of an architectural project, and a design process, but the seemingly hidden structure and agency of these relationships. It is necessary to confront these agencies; to position oneself as one of them, and an observer of them. Only by admitting this key space into consideration (for us the most important and least studied space in the discipline) can we move from the misdirecting ‘neatness’ of conventional architectural engagement and criticism (in which our agency as observers is subsumed by the coding of the image(s) and their coercive capacity to enforce a way of being read) to a more careful and considered negotiation of meanings, a critical and performative, generative dialogue that allows us a position on a shifting, assembled surface of affect and make decisions about what is being communicated, and what we want to “make” of it.

DIGITAL AGENCIES

In the past 30 years, the studio as a cohesive space in which the designer operates with a fixed and specific bodily relationship to the representational media within has shifted into a space in which representations exist at a flexible range of scales and states, engaged with a fragment at a time. This dissolution of the studio as a material environment that contains and holds the author of design work in a clear relationship to the design work has had multiple consequences. One has been the reduction of significance in the action or gesture of engaging with representations, and in particular multiple representations. This is largely the result of the number of digital processes the designer engages with in the production of architectural projects. As decisions are made through CAD, the project becomes responsive to the agency of the programmes used and the controlled nature of the spaces they operate in. In brief, one consequence of the move to digital production is a reduction of the capacity to observe or experience multiple elements of an architectural project at any one time.

One response to the digital, rather than capitulating to its fragmented and disconnected coding of spaces, might be to re-evaluate and give greater potency to the spatiality of the studio itself, with close attention to the configuration of its many parts and our relationship to them. This would help balance and combine the Cartesian rules and obsessions of the digital and its capacity for extreme – arguably excessive – precision (Hughes, 2013) with

other constituent parts of a work, which are interpreted and understood in other ways. This spatiality can only be considered if meaning is attributed or acknowledged to the relationship between the digital aspects of a project and its non-digital counterparts. If these things are positioned in a dialogue, we can position ourselves in the space between them and observe and interact with them equally. This necessitates a shift from the priority of our focus away from the individual representations that normally preoccupy us, and concern ourselves instead with the structure of the design project itself as a spatial configuration; a contextual field that engages varied elements of a work with each other, with ourselves, and that demands an embedded understanding of the whole and our position within it.

ANIMATE LANDSCAPES

Our project *Animate Landscapes*, published as *Pamphlet Architecture 32: Resilience* in the long-running series, was the foundation for our interest in the studio space. Our site for this project was an uncertain territory in Wola, east Warsaw, akin to us as a location of Andrei Tarkovsky's *Stalker*, abandoned train carriages sitting as blackened husks in the November fog. The vacancy and stillness of the landscape reverberated with a sensation that the serenity of the place was under threat or was an illusion. In order to capture the complex qualities of this Zone, somewhere between tranquillity and vulnerability, it seemed necessary to search for an appropriate representational mode. It became apparent to us that the best way to work with these qualities in our studio in Edinburgh would be to work with found objects – physical fragments that resonated with the landscape in some way, while at the same time enabling and encouraging the possibility of new meanings layered on through observation and interpretation.

For us a metronome (Figure 1) acted as a vessel for the landscape; preserving its qualities through its symbolisation of time and stillness. The metronome acted as the first in a series of objects (Figure 2) that we introduced to represent the landscape in Wola. In the collection of these objects – “*precisely the kind of fragile, intimate objects... that disappeared with the systematic erasure of domestic space in Warsaw's mid-century trauma*” (STASUS, 2012), layers of meanings were curated and coerced into dialogue with each other, and us, through their manipulation and transformation, the studio space we occupied began to fill – or became possessed – by a new type of territory. In the collection, “*time is not something to be restored to an origin, rather, all time is made simultaneous or synchronous within the collection's world.*” (Stewart, 1984). Together, in the studio, the collection formed a cohesive entity. The project that emerged through them (Figure 3) allowed the observer (and ourselves as designers) to drift through scales – the immediate scale of the object, and the scale of the representation they held – as the space between and around them is negotiated. Instead of looking through the space and discounting its properties, we are embedded within it, and the space of the studio itself becomes infused with the meanings and potentialities of architectural representation it contains.

We can no longer assume the space is neutral; it becomes part of the architectural work. The individual framing of architectural images breaks down and we enter a space which becomes in itself representational. The meanings and codes we associate with everyday objects such as a chair meet and mingle with the phenomena we're looking for in representational devices, images and models; urban topographies mix and meld with shadows, scratches and dust on the surface of the studio floor. This space allows itself into the generative, performative act Evans describes as the reading of architectural images, in which our imagination allows structures to blossom. Rather than a notionally neutral framing of these images, as we conceivably might find in the art gallery, we allow the



▲ Figure 3 The Room

space around the objects and images of the project to interact with them and enter into its language. By accommodating this territory, and ourselves within it, the project becomes as much about the spaces between representational devices as the spaces behind the framing of representational devices. We step into the project and are surrounded by it - *“... the project is a dream of things in which the viewer plays the role of the dreamer.”* (STASUS, 2012).

ERASURE OF SUPPORT

Animate Landscapes embodies for us a model of the studio – the space around representational devices – that can heighten the experience of architectural projects through its admission into the work, in both its production and critical interpretation. Landscape in the title refers less to the expansive site in which the project notionally operated in Wola, Warsaw, and more to the condition of the studio space in which it took place. A landscape in this sense isn’t something to be observed, or even comprehended, exactly, but is more closely related to *“the dream of things”*. Lyotard discusses the true experience of landscape as *“an erasure of support”* and *“a vanishing of a standpoint”* (Lyotard, 1991) in which expanse overwhelms and disorients the observer. By admitting the space in which critical interpretation takes place into the contextual field of the architectural project, there is a usurpation of conventional critical roles and normative modes of understanding architectural representation, and a subversion of our expectations as critical observers. It is destabilising, and potentially dangerously so: without a clear relationship between observer and observed object, a critical interpretation may end up

impossible. The blossoming of design elements in the mind may never take place, due to the instability of our observation: without the limits of the work clearly demarcated, the critical position we hold from which to observe work risks being untenable. This is why, after all, the studio (or any space in which architectural representation is held and examined) is usually discounted in a reading of architectural projects in favour of a clear framing of architectural imagery. What we propose (and what our projects attempt, alongside our studio teaching) is that the admittance of this space has to be managed in a particular way. It has to be designed in the production of projects. In fact, the designing of this space and our relationship to it is a means by which to thematise and propel architectural design.

For *Animate Landscapes*, the coding of this space was derived from the relationship of our collection of fragile objects to Warsaw's destruction in World War II. The fragility of the pieces, and their material condition, spoke directly to an absence at the heart of the city. In acknowledging this, we could communicate aspects of Warsaw's material histories through an interaction with and manipulation of the material conditions of the studio. In this way, the observer of the project is made aware of the studios potential as allegory for the material condition of the city, and the resulting experience helps frame the relationship of observer and representation. In the following projects and studios, this coding of this space and the relationship between observer (designer) and representation is always of key significance. It is a theoretical framework embedded into our work on a more fundamental level than the aesthetic concerns that often guide architectural image-making. In one sense, it is the ambition of this work, in its acknowledgement of the space around and between architectural representations, to allow us to design this space as a critical part of the production of architectural projects, and to programme our engagement with the project both as designers and critics. In other words, to design the spatial framework in which the performative act of interpreting architectural projects takes place.

EVEREST DEATH ZONE

We tasked ourselves to utilise this conceptualisation of architectural representation to address spaces far beyond the notional remit of architectural representation. This is more a question of experience than size – as the tools with which architectural designers operate have always been able to convey and image vast differences of scale. More recently, narrative architectural projects have made extensive use of allegory to reflect and communicate ideas using traditional story-telling techniques. The novel has been widely used as the basis for architectural projects, through key texts such as *Alice in Wonderland* and *Gulliver's Travels*, and cinematic concerns have more and more become a key component of architectural schools and pedagogical approaches. While we are attracted to the potential uses of narrative derived from these forms in architectural projects, we are attempting to dissolve the limits of the framing of representation through an acknowledgement of the role of their critical interpretation, and the space that is communicated. Because of this, the novel or film aren't ideally suited for our studies as both tend to discount the action or gesture of reading or viewing. Instead, we look to forms in which the observer is regarded more clearly as an active participant: the art installation, and performance.

The International Necronautical Society's manifesto, published as an advertorial in *The Times* newspaper on December 1999, reads among its aims: "*Death is a type of space, which we intend to map, enter, colonise and, eventually, inhabit.*" (Crichtley, McCarthy et al., 2012). In our project *Everest Death Zone*, we attempted to realise this ambition through the mapping and inhabitation of the space of death in relation to some of those



▲ Figure 4 Mallory



▲ Figure 5 Everest Death Zone Installation model. Photograph by Joe Dent

endeavourers who lost their lives ascending Mount Everest. We started by producing a representation of George Mallory's ill-fated attempt to scale Everest's summit in 1924. Mallory and his climbing companion Andrew Irvine were the first recorded deaths of over 200 people who have died in the Everest Death Zone. In this permanently frozen terrain, which exists 8000m above sea level, is a kind of purgatory for those who were unable to ascend, literally – perhaps also figuratively. Our image attempted to capture this merging of body and landscape through an analysis of the events that led to Mallory's death, and the ambiguity surrounding the possibility of his summit attempt: did he reach the top or not? The image (Figure 4), appearing as a black cavernous vessel, represents the position of Mallory's body when it was discovered in 1999. It depicts the view he would have had towards the summit from the location of his body alongside the last recorded photographs of him in relation to it. The surface of the mountain itself is abstracted into a limitless wireframe mesh.

The bodies which occupy the Everest Death Zone, each frozen in the moment of dying, undergo a form of transcendence. In this permanent expanse of whiteness the landscape is a kind of void, and the frozen, human forms are all that remains of highly specific moments in time and space. Their specificity is born from their preservation and the bodies often take on new roles as landmarks as navigational aids for the living. Individually, they tell us a story of their death and, collectively, in their persistence, they map a landscape of a unique mode of dying: for some horrific, desperate and lonely and for others, perhaps euphoric. Charting Mallory's endeavour, a map was created which conflated key events of the ascent with the geometry of the mountain. The result was the creation of a space that recognised death not as a static event, but instead a field of specific moments that exist around death. Such a representation is not possible in itself, but is possible through a performative interpretation of the image. By positioning the observer in the role of Mallory, we are able to act out his death and understand the landscape and his relationship to it in a new way. This works to some degree with a performative reading of the image, as it is understood in a particular way when the thematic is revealed and the reference made clear.

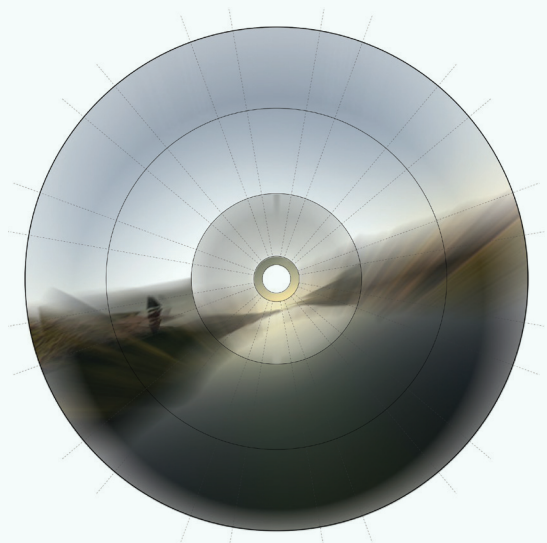
Everest itself plays a role in this understanding. The mountain, so heavily visualised and embedded in the cultural imaginary, is inescapable – for these unfortunate climbers but

also in the wider sense that it appears so determinate as a thing in itself. The silhouette of the mountain, for example, is immediately recognisable, and the cultural associations of Everest are well-understood: the insurmountable task, the near-impossible challenge of a “personal Everest”. By conflating Mallory’s failed attempt with the surface of this symbolic landscape, we are forced to attempt a deeper reading of Everest and its implications. The body, depicted in the drawing as a black smear on the landscape, is suspended in the abyss of the unknowable and heavily abstracted mountain. The transformed body itself, known as the subject through the image’s title Mallory, appears through its formlessness, like a disfigurement of the corporeality of the observer – “the panic comes from the fact that the narcissistic imago of the perceiver has been attacked” (Bois, YA. and Krauss, RE., 1997). The familiar form of the mountain is also gone, replaced by an ambiguous terrain, although the mountain’s recognisable silhouette is visible within the photographs in the representation, dwarfed by the body-form. We are invited to inhabit the space surrounding the death and to meld, even transcend, into the landscape like Mallory and the other endeavours of the Everest Death Zone. In this way, we too become part of the event and part of the landscape, becoming inhabitants of the space of death. We are performing a reading of the spaces suggested in this representation, through our understanding (or lack of) of its associations: Everest, endeavour, mortality, etc.. We are caught in a moment of understanding that constitutes a different kind of landscape, to return to Lyotard’s *SCAPELAND*, in which landscape is understood as an erasure of a support. We are not attempting a description of this landscape, but a form of “the writing... of the impossible description; *DESCRIPTURE*.” (Lyotard, 1991) This allows us to take a position and – if only fleetingly – glimpse or even inhabit (as the INS propose) the space of death.

The next stage for this project translates the drawings produced into an installation in the studio: a space in which elements of the image are re-formed and inhabited (Figure 5) and the original image is, in part, reformed through shadow and projection. Working with students in Newcastle University’s innovative *Linked Research* model, the installation allows us to reflect on the Mallory-object as a container or vessel for a body. We can enter it and from within, observe the summit through its representations in the film *The Epic of Everest*, using footage from the original summit attempt and recently restored by the British Film Institute.

LANDSCAPES OF HUMAN ENDEAVOUR

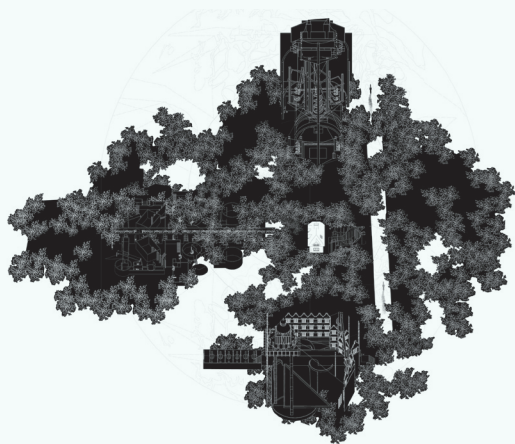
An MArch studio developed from *Everest Death Zone* at Newcastle University, titled *Landscapes of Human Endeavour*, which furthered many of its themes while allowing students to identify their own endeavourer (and associated landscape), and so explore new ways of interpreting both through the performative framing of architectural representation in the studio space. The projects were varied and fascinating, ranging from a project based on Donald Campbell’s doomed water-speed record-attempt on Lake Coniston (Figure 6), to Michael Collins’ solitude orbiting the far-side of the Moon in the Apollo 11 missions; a project which developed into a printed data-landscape held at a Lagrangian point in deep space (Figure 7). As with *Everest Death Zone*, these projects were installed in often complex ways. Most interesting, perhaps, was Alicea Berkin’s *Architectural Biography of T.E. Lawrence* – more commonly known as Lawrence of Arabia. By reconfiguring his experiences in the desert, and key moments from his life as described in his autobiography *The Seven Pillars of Wisdom* (Figure 8), Berkin generated a series of seven forms that surrounded Lawrence’s retirement cottage in Clouds Hill, Dorset. The forms become a manifestation of Lawrence’s psyche, and exist in an ambiguous territory between real and mirage afforded by architectural representation’s ‘unfixed’ nature. On observing the representations of Berkin’s seven architectures, we are unsure if they are proposals for the



▲ Figure 6 View of Event-Field. Image by Will Slack



▲ Figure 7 Data-Landscape fragment. Image by Tom Lobb



▲ Figure 8 Seven Pillars of Wisdom. Image by Alicea Berkin



▲ Figure 9 Installation Photograph



▲ Figure 10 Photograph of Installation at Clouds Hill

project's ostensible site around the cottage, or whether they are fantasies projected from the windows of the cottage onto the landscape around it by Lawrence. In our reading, we realise the spaces that are being presented are in themselves a form of imaginary landscape: a landscape of memory constructs and desert imagery; haunting reminders of events and spaces reimagined into tangible forms. Our expectations are overlaid with Lawrence's, and our reading of the landscape and of Lawrence are amalgamated. Through Berkin's installation, which was modelled as an abstraction of the cottage in Dorset to which Lawrence retired, we are placed in the role of Lawrence (Figure 9), and we are both witness to and embroiled in an understanding of the individual, hence the project's autobiographical nature. The work was ultimately installed in a 1:1 construction in Clouds Hill that recreated, in abstraction, the cottage and located us within it (Figure 10). The drawings and representations were in themselves ambiguous in a reading of Lawrence's life, but also the props (a writing desk and typewriter, images from the famous movie of his life, even the relationship of the installation to his cottage with its own National Trust museum) allowed an interpretation, never clear, questioning his values and experiences, and the cultural memory attributed to him. It is the spatialisation of the project in this way that allows us to engage with its subject: we are immersed within his world, performing his experiences as opposed to simply observing them.

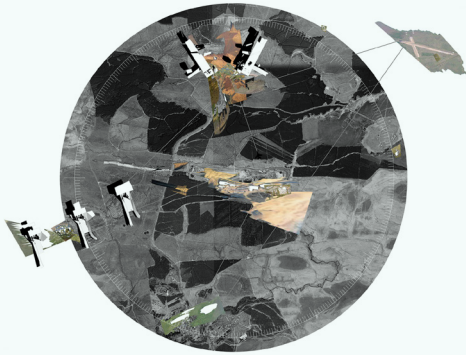
THE TRANSFORMATIVE GAZE

If, as engaged participants in the production of architectural projects, the space that we design in, the framing of our relationship to work, and the agencies of the modes and media we utilise all have an effect on the nature of our engagement with architectural projects, there is another aspect to consider: the nature of our seeing. Our projects and teaching have concerned themselves with modes of looking at architectural representation and we have found it helpful to explore this in relation to military agencies; adopting militarised viewpoints to reveal embedded agencies within the act of observation. When a soldier sights a rifle, it has a special significance:

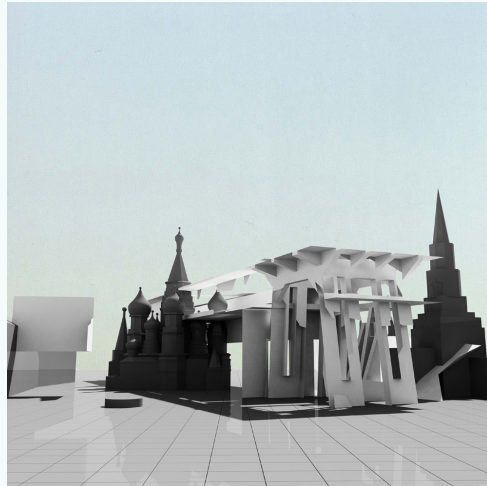
"The soldier's obscene gaze, in his surroundings and on the world, his art of hiding from sight in order to see, is not just an ominous voyeurism but from the first imposes a long-term patterning on the chaos of vision, one which prefigures the synaptic machinations of architecture and the cinema screen." (Virilio, 1989).

The battlefield soldier of the late nineteenth and early twentieth centuries, in sighting and subsequently framing a view and focusing upon it, Virilio argues, is a precursor to the viewing that we now take for granted: the vision of the camera supplanting our own vision. For him, this served to increase *"the depth of visual field while reducing its compass"* (Virilio, 1989). The view framed by the soldier detaches the observer from their surrounds. This militarised view is a precedent for all technological modes of seeing. The distance that the soldier's gaze encompasses is not simply physical space but technological: a time-line tracing the disruptions the military advancements of the 20th century impacted upon visual practice and philosophy.

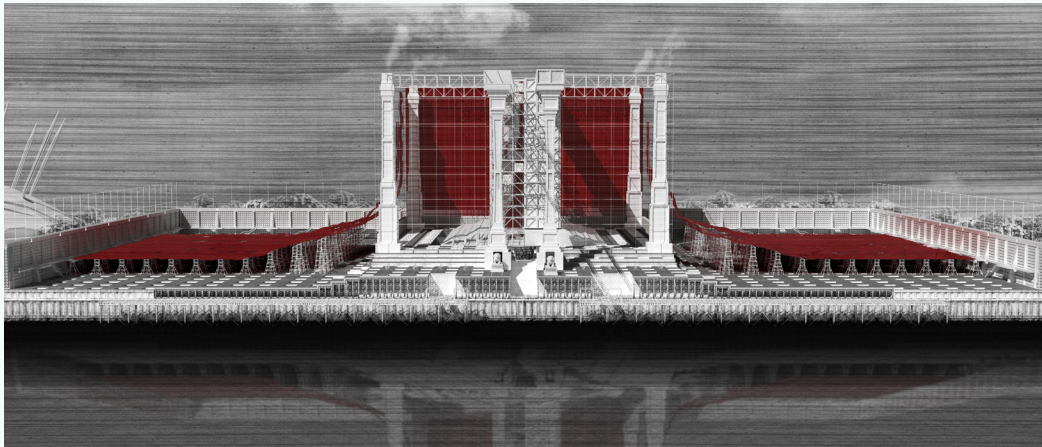
In an MArch studio we ran at Newcastle University titled *Parallel Military Landscapes*, students were asked to recognise and adopt this viewpoint in the representation of their chosen projects. All modes of viewing the work, even our engagement as critics, became problematized by the agency of militarised sight. Our student Adam Smith presented the RAF base Spadeadam through fragments of online imagery taken of it (Figure 11). In this way, the technological vision of Google Earth was turned back on its military precedents and the resulting landscape is a fragmented, dissociated whole, filled with gaps and



▲ Figure 11 Spadeadam Fragment Model. Image by Adam Smith



▲ Figure 12 Courthouse intersecting with St. Basil's Cathedral. Image by Adam Smith



▲ Figure 13 Monument to Nelson. Image by Alex Fotherby

impossibilities where images, pixilations and distortions collide. Smith used this reading to represent his project as it developed in Moscow, re-formatting and presenting the city as a parallel landscape of militarised views. This site operated between the technological vision of the military and the real Moscow. The city thus becomes reconstituted and a programme is violently inserted into the gaps and glitches within and between viewpoints (Figure 12). Rather than fitting his proposal into the site Moscow offers, he instead recalibrates his site, the urban context in Moscow, and his architecture along with it, into the discontinuous space offered up by the militarised sighting of his project. The proposed architecture is forced to exist within this charged space of representation, and in particular the gaps and glitches where these spaces don't add up into a consistent whole because of the nature of the optics used. From this, the programmed areas of these hidden and discontinuous spaces became secretive and Kafka-esque; they contain the unseen mechanisms of state control drawn from contemporary discourse on Moscow. The structures demonstrate through their attempted realisation the impossible spaces of militarised sight and so

question the notional accuracy of spatial representation in the modes of vision employed by the military, and ourselves as architects. Through an examination of the spaces and references his project draws in, it becomes apparent that what we are looking at is not so much a coherent and continuous series of spaces projected onto Moscow, but instead a contextual field that draws things together into a (fragmented) whole and asks us to engage with it in the studio. By drawing attention to both the agency of observation and the seemingly familiar nature of urban representation (through Google Earth, etc.), the nature of both is questioned.

A related brief at the University of Greenwich asked students to interrogate the collection of the National Maritime Museum. Within the museum in Greenwich there is a special collection entitled *Nelson, Navy, Nation*, which celebrates the supposedly heroic life of the British naval officer and military strategist Lord Horatio Nelson. For the viewer, this historical exhibition represents a powerfully cohesive whole – a completeness which avoids speculation and interpretation. For the purposes of the design brief, students were asked to select a particular object from the museum collection. The intention of this request was to allow new meanings to be projected onto these dislocated objects through their close consideration and reworking. One of the students, Alex Fotherby, selected the bullet-strewn undress coat worn by Nelson at the Battle of Trafalgar, 1805, where he was famously shot and killed. On freeing the jacket from the context of the museum collection, the observer is able to see beyond the formal constraints of the garment. Instead, the jacket became viewed as something which had lost its form, and context, and is thus opened up to the observer's projections. As the formlessness of the jacket is revealed, the hole left by the fatal bullet engulfs the viewer as the principal point of focus, moving the ceremonial appendages adorning the jacket to the periphery. Upon viewing the void of the bullet hole, the observer steps into the space once occupied by Nelson's killer, and in taking up this positionality, the viewer begins to occupy the space of the soldier: a space of ominous voyeurism.

For the student, this occupation enabled a way of viewing, or sighting, the project that consisted of a series of drawings exploring interval perspectives towards the void of the hole from the point-of-view of the bullet. These perspectives were then collapsed into the moment of impact to generate a new hybrid form representing the visual trajectory between viewer and object. This form is the result of both the unpacking of the bullet's trajectory and the formlessness of the bullet hole. Within this cone of vision, both projections meld together to represent the moment of Nelson's death as a complex topological field. The inhabitation of such a space is possible on a number of levels. First, by observing the bullet hole we fleetingly inhabit the moment of death. Second, by mapping and charting this moment, it is possible to construct a spatially complex environment drawn from it. This cartography of death set up a number of spatial parameters, creating a vessel in which the architectural immanence of the project is revealed. The project became a vessel, sited in the zone between the location of the jacket in the museum collection and the passage that Nelson's body took during his Thames funeral procession near Greenwich. This new vessel for Greenwich – a reworked monument to Nelson (Figure 13) – consists of the instances that have been mapped between the viewer and the object.

Vision and its relationship to design processes and decisions is rarely given a role as a constituent part of the production of spaces within a work. However, as demonstrated here, visual agency is a key component of critical engagement with design work. We should distrust modes and media that take our vision for granted; the ubiquitous vision of Google Earth, the internalised logic of the computer-generated perspective; and which are used

commonly and without critical interpretation in the production of architectural work. The projects above attempt to accommodate vision in its most violent form: the obscene gaze of militarised thought. As the gaze becomes spatialized, the means by which we observe the work is brought into focus. We are tainted by its associations, and the projects, and our understanding of them, reconfigure themselves around this new and unfamiliar mode of looking.

CONCLUSION

Our practice and pedagogy are constituted in zones of between-ness – the studio space that holds us, and the objects and spaces that we are observing. This space is one in which images, objects and their observation are bound together in a continuous, performative dialogue that mediates their understanding and role in the design process and its varied outputs. The space of our practice does not really exist in the spaces of the images and scale models, digital representations and collages we and our students have produced, nor in the material makeup of the walls, the floor, or surfaces of the studio. The space of our practice exists between all these things and ourselves, and is visible only in fleeting, performative interpretation and moments of understanding. Each understanding may be, even subtly, different. And from a continued process of observing, reading, and communicating with our work (and the work of our students), a studio practice emerges which is constantly transforming. It is within this conceptualisation of the studio, as a contextual field of indefinite potential in which we are always engaged with our projects and their resonances, that we produce and ask students to produce architecture.

Recently, architectural representation has by necessity been required to move beyond its traditionally static and self-assured forms. In doing so, it has opened up all sorts of questions on the nature of not only architectural representation but architecture more generally, and there is ongoing dialogue about the role of architectural education in responding to this. How do we represent spaces we know are transient using coding designed to express permanence? How do we make use of the digital's capacity for precision, while remaining aware that the real is not so precisely defined? What is the relationship between the designer and the production of work, given the range of media and practices utilised that each has its own embedded agency? The media we use to produce and present work often goes unquestioned. However, in the discipline more and more architectural thinkers have been awakened to the capacity for architectural representation to craft a dialogue between seemingly disparate but connected things. This capacity of architectural representation as being able to image, outline and make tangible ideas is striking, and more theorists and practitioners are helping to redefine the role of architecture to focus on this spatiality of meaning. Our approach, outlined here, focusses on the space that holds representation as significant and programmable, in order to allow for a critical relationship between ourselves and our work: one that celebrates and enhances our embodied understanding of architectural spaces rather than muting or ignoring the space in which we critically approach work. Our interpretation of these representations and the contextual field that surrounds them in the studio space, and our positionality in relation to this space during the production of and in the performative interpretation of work is, pertinently for any consideration in this discipline, principally a spatial concern, and so worthy of further consideration in the architectural discipline.

REFERENCES

- Bois, YA & Krauss, RE, *Formless: A User's Guide*, Zone Books, New York.
- Critchley, S, McCarthy T, et al. (eds.) 2012, *The Mattering of Matter: Documents from the archive of the International Necronautical Society*, Sternberg Press, London.
- Deleuze, G 1988, *Foucault*, trans. S Hand, Continuum, London.
- Evans, R 2000, 'In Front of Lines That Leave Nothing Behind' in Hays, KM (ed.), *Architectural Theory Since 1968*, new edn., MIT Press, Cambridge MA.
- Haralambidou, P 2013, *Marcel Duchamp and the Architecture of Desire*, Ashgate, London.
- Hughes, F (ed.), 2013, *Drawings That Count: The Work of Diploma 15*, Architectural Association Publications, London.
- Lyotard, JF 1991, *The Inhuman: Reflections on Time*, Stanford University Press, Redwood City.
- STASUS [Firm] Craig, JA & Ozga-Lawn, M 2012, *Pamphlet Architecture 32: Resilience*, Princeton Architectural Press, New York.
- Stewart, S 1984, *On Longing: Narratives of the miniature, the gigantic, the souvenir, the collection*, Duke University Press, Durham NC.
- Virilio, P 1989, *War and Cinema: the logistics of perception*, Verso, London.

Design Research in Architecture: The Path towards Research-Based Education

Professor Murray Fraser

The Bartlett School of Architecture, UCL, UK

This paper will begin by asking two key questions: firstly, why has architectural education been so resistant for so long to the acceptance of research within its own practices; and secondly, as a consequence, what is the best way for us now to get around the impasse? Historical reference will be made to the work of figures like Leslie Martin and Richard Llewelyn-Davies in the 1950s and 60s, through to the impact of critical theory, cultural studies and digital design from the 1990s, none of which however made a fundamental change in terms of the teaching of studio design in architectural schools. This paper will instead argue that it is the advent of the approach known as design research in architecture over the past two decades that offers the first genuine opportunity to create not only research-based design, but also research-based practice.

The argument will be developed using the points which the author has written on extensively in regard to how research needs become embedded within architectural practice and the teaching of the subject. The other source of evidence for the paper will come through the analysis of a specific range of architects which has been deliberately chosen to include both speculative (Lebbeus Woods, etc) and applied practitioners (Teddy Cruz, Shigeru Ban, Tonkin Liu). The latter category will also allude to the approach used by the Palestine Regeneration Team (PART) for research-based projects in the West Bank and Gaza Strip. Then, to show how such approaches apply within education, a few examples of design-based student work will also be shown.

Above all, by demonstrating and promoting the broad church that is represented by design research, and by discussing how this approach can be embedded into the educational process for forthcoming generations of architects, a range of suture opportunities will be suggested. Here the argument will be developed not merely on the usual aesthetic and pedagogic grounds, but also in regard to the general role and status of architects politically and economically. In this regard, the paper will conclude with reference to Cedric Price, who in essence first presented the case for an educational model based on design research back in the AA during the 1960s (even if that particular aspect of his work was overlooked at the time due to a focus on other dominant tropes).

DEFINITION OF DESIGN RESEARCH IN ARCHITECTURE

As a working definition, architectural design research can be described as the processes and outcomes of inquiries and investigations in which

architects use the creation of projects, or broader contributions towards design thinking, as the central constituent in a process which also involves the more generalised research activities of thinking, writing, testing, verifying, debating, disseminating, performing, validating, etc. Architects have been deploying a combination of these modes of expression for a rather long time in their work: for around 500 years now, according to my esteemed colleague, Jonathan Hill.

Likewise, design research is able to blend into other more established research methodologies in the arts, humanities and science, with no intrinsic antagonism. It is vital that the design element and these other modes of research activity and research methodology operate together in an interactive and symbiotic manner, with each feeding into the others throughout the whole process from start to finish. In turn this raises an important point about temporality, in that design research should never be something that just happens at the beginning of a project, as a sort of Research & Development stage, before the architect 'lapses' into more normative and routine productive modes. Indeed, architectural design research, if undertaken properly, is open to the full panoply of means and techniques for designing and making that are available to architects – including sketches, drawings, physical models, digital modelling, precedent analysis, prototyping, digital manufacture, interactive design, materials testing, construction specification, site supervision, building process, user occupation, user modification, etc. Architectural design research does not of course need to use all of these possibilities in every instance, but they indicate the sorts of techniques that ought to be brought into the frame.

Design research in architecture cannot however be conceived as synonymous with the immensely broad subject of architecture, or indeed of architectural practice; rather, it is a significant seam that runs through design work with a particular focus on the creation of new insight and knowledge. Here there is a useful parallel with practice-led research in the fine arts, as Jane Rendell has pointed out. She notes that compartmentalising the four main disciplinary approaches within architecture (building science, social science, humanities and art/design) works directly against what we realise is the multi-disciplinary nature of architecture as a whole. Instead, Rendell believes that design research offers a means to bring these disciplinary strands together and also – importantly – for them then to be able to critique their own methodological assumptions. In this regard, architecture can learn a lot from the development of PhDs by Practice in other artistic fields. Yet while accepting that the influence of practice-led research in the fine arts is important, there are of course other approaches within architectural design research which stem from very different impulses: there are many types of research in design research, just as one can see there are many types of research in science or social science or history or fine art.

This then leads on to the issue of the methodology of design research. Other forms of research in architecture openly proclaim their methodological approach, for example science (repeatability) or history (transparency), while in social science, for instance, an articulation is made between theory-testing (deductive) and theory-building (inductive) approaches. Yet in each case, research methodology is not just a narrow matter of being rigorous and consistent and diligent. The importance of speculation and imagination to the scientist, or the social scientist, or the historian, is well testified. Hence the only difference with design research in architecture is a matter of degree, since in the latter – while borrowing where appropriate from the other, more established research methodologies – the creative aspect becomes the dominant part of the investigation, and to achieve that it has to introduce its own ideas of testing and evaluating, even in rather lateral or unexpected ways. Hence there is no methodological schism. Each of the other kinds of architectural

research also rely on creative leaps and lateral thinking in their methodological process, if not nearly as much. In other words, the issue of the methodology of design research as a contested site – in that it clearly opens up a new paradigm of research – is one of its real strengths.

As a key example, I am fascinated by what is, as far as I know, the first specific reference to design research in architecture, by the Finnish émigré architect Eliel Saarinen in a book titled *The City*, written in 1943 in war-time America. In the final section of his book, Saarinen postulated a scenario in which the research component of their work involved architects in imagining what a city might be like in 50 years time, and then extrapolating their thoughts backwards in 10-year jumps in order to meet up with, and thus inform, their more practical work to design projects required to construct that city. For Saarinen, it thus involved a two-fold movement that expressed well the desire of the architect to be able to imagine in different temporal zones – from present to future, and from future back to present – in their designs. It reminds us the complex and varied methods required to conceive innovative and relevant architecture.

This degree of openness – both in the acceptance of design research as a valid activity and in what it involves as an actual practice – is of course highly relevant. We know that architects, through their design work and professional practice, carry out forms of research that produce their own particular kind of new insight and knowledge. In other words, they are engaged upon a research process that is noticeably different from, yet equal in value to, the kinds of insight and knowledge from natural scientists, social scientists, historians, geographers, humanities scholars, etc. It is essential to hold this catholic and tolerant view of design research, for if there has been a weakness in previous thinking on design research in architecture, it was that they were far too defensive. In turn this caused writers to attempt to justify design research in terms of what it was not – mostly in relation to misconstrued or exaggerated notions of objectivity in the natural sciences – rather than trying to say what it actually was.

THE RESISTANCE TO ARCHITECTURAL RESEARCH

This then leads me on to the discussion of why there has hitherto been such resistance to the idea of architects' work as incorporating what I define as design research. It is worth remembering that architecture is a subject often riven by passionate schisms: the heated 'Art or Profession' debate in 19th-century Britain was witness to that. Similar antagonism was also found when those who first championed the idea of architect-as-researcher back in the 1950s and 60s, of which in Britain the two leading exponents were Leslie Martin at Cambridge University and Richard Llewelyn-Davies at the Bartlett School at UCL. The Rubicon however appeared to have been crossed at the 1958 Oxford Conference on Architectural Education, which set out a vision of architecture fully embedded in the expanding post-war university world, removing it thus from any surviving vestiges of apprenticeship in practice. Architecture was called upon to become part of the 'white heat' scientific revolution.

The latter appeal was very much the battle cry of Leslie Martin, who founded a highly cerebral model of architectural research that focussed on land-use studies and environmental design at Cambridge, later codified into the Martin Centre. At UCL, Richard Llewelyn-Davies took an allied but slightly different approach, one that followed the American model of the Bauhaus as established over the Atlantic by figures like Walter Gropius at the Harvard Graduate School of Design, and others. At the Bartlett from the 1960s, architecture was merged as part of the expanded capitalist construction industry,

and undergraduate students were taught sociology, geography and other disciplines in the manner of an American liberal arts degree. What was missing in the Llewelyn-Davies vision was the actual process of design, a subjective and imprecise activity best left to the non-scientists at the Architectural Association and elsewhere. By the 1970s the joke was that Bartlett students could plan everything but design nothing, while the AA students could design everything but plan nothing.

The positivistic approach to design research promoted by Martin and Llewelyn-Davies, and supported by other scholars of the time, such as those from the Design Methods camp, was too reductive and simplistic for most British architects and academics. Appeals to science meant little if issues such as bodily scale, aesthetics, power, atmosphere and other aspects of architecture were excluded from the discussion. Design research was given an image of positivistic reductionism that sees certain architects to this day still denying that their work can be regarded as research, as if somehow that would drain them of any claim to creative inspiration. But one cannot simply blame scientific positivism. Later on, in the late-1980s and early-1990s, the impact of critical theory, cultural studies and digital design failed to make a fundamental change in terms of the teaching of studio design in architectural schools, since they did nothing to ensure that research expanded beyond the traditional spheres of history and theory, or technology.

NEW VISIONS FOR DESIGN RESEARCH IN ARCHITECTURE

A major impetus for a new vision of design research came from the mid-1990s with the creation of the first PhD by Design programme in an architectural school, by Philip Tabor and Jonathan Hill at the Bartlett in 1995. Their model came directly from the PhDs by Practice that had been set up in British art schools a few years before by the likes of Adrian Rifkin. Soon after the Bartlett, a different model of the PhD by Design was created on the other side of the world by Leon van Schaik at RMIT University in Melbourne, as an attempt to bring high-quality practice work into the academic fold. Today there are many PhD by Design programme in Europe and Australia, which cover a great variety of subject areas including design method, visual representation, textual analysis, social processes, and strategies for action. Design doctorates need to contain a substantial amount of serious and innovative historical/ theoretical research as written text, with this being combined with creative propositions realized through a symbiotic mixture of drawings, models and textual analysis. In this regard, the actual projects might well be drawn, built, filmed or rely upon a range of other investigative media. Yet in all cases a deeper textual analysis absolutely has to be present. Indeed, it is this essential symbiotic interplay between designing and writing which creates the essential framework for a design doctorate in architecture.

Equally important to us today are the innovations in design research in architectural practice, in many cases from those also teaching in architectural schools where a strong PhD by Design programme exists. At the Bartlett a clear example of this is Niall McLaughlin, who is now trying to reshape his much-decorated practice on the basis of design research. As an exquisite example, his research process for the Bishop King Edward Chapel outside Oxford involved him in a very deep study of geometry in an attempt to find a contemporary way to link architectural design to religious liturgy, including here an exercise with those in his office to create a modernised version of the medieval tracing floor so as to get around the dull dominance of computer-generated geometries in contemporary architecture. Another excellent example is the work by Mike Tonkin and Anna Liu in developing what they call Shell Lace Structures. Funded in part by the RIBA, and working closely with Arup Engineers, their investigations have involved also research work by a postgraduate design studio they taught at Westminster University.

Outside Britain, who might we point to as coming up with new ways for design research in architecture? One obvious figure is Teddy Cruz, working (and worrying) on the American/Mexican border. Cross-border trade in legal and illegal goods has created a volatile cultural condition in San Diego, where Cruz has his practice, and even more so directly over the border in Tijuana. As someone who comes from Guatemala, Teddy Cruz is more than happy with cultural hybridity. Indeed, part of his work is to map and analyse these acts of hybridisation, whereby off-the-shelf or recycled components from the USA are recycled in the suburbs and shanty towns of Tijuana, including entire prefabricated houses. Aware of the sheer extent of self-build and creative energy being supplied from below, Cruz has a number of projects that tap into the flow, often using 'problems' like property rights and other legal constraints as design generators. His schemes consciously mix ideas of scale, either for contained mixed-use buildings, or for medium-scale housing districts based on the values of the individual hybridised dwelling unit. Cruz claims it is the neighbourhood, not the city as a whole, which forms the urban laboratory for the globalised conditions of the 21st century: he terms them as 'micro-heterotopias'.

Teddy Cruz's work openly echoes that of the late and much-missed figure of Lebbeus Woods, whose political challenge to the way in which architectural space is generated within our cities, and against the seeming hegemony of those who dominate computer-aided-design, was seminal. It was Woods who made the now common assertion that war and natural destruction, for all their terrible consequences, also enable chances for change. In this vein, a project that vividly expresses the kinds of subtleties now required by global economic conditions is the remarkable scheme by Shigeru Ban – an architect currently spending much of his time on post-tsunami reconstruction work in eastern Japan – for a 'transitional' cardboard cathedral for Christchurch in New Zealand. As a relatively prosperous city that was devastated by a particularly deadly earthquake in February 2011, Christchurch has insufficient funds to rebuild itself as it once was, plus it has lost about 10% of its population and it is uncertain if it can ever regain its hitherto economic status. There has also been a series of subsequent aftershocks. In such a situation there could be despair, but instead the local priest has engaged Shigeru Ban to create a cathedral for 700 people that can be erected in a matter of months and which is 'only' intended for a 20-30 year lifespan. The design is a work of real ingenuity, playing upon Ban's longstanding sensitive and dramatic use of cardboard tube construction, backed up this time by ritualised visual devices such as coloured glass to give it a suitably religious sensibility.

DESIGN RESEARCH IN THE ARCHITECTURAL STUDIO

The new, inclusive and creative approach to design research is also changing and enhancing the teaching of architectural education. It is a subject that I not only write about generally, but also encourage in the students that I teach in design studio – first at Oxford Brookes, then Westminster and now the Bartlett. My fundamental principle is never to set a specific site, or a specific brief, but instead merely propose a theme that each student has to investigate themselves to devise their own spatial proposition for how that particular aspect can be used to make cities better places to live.

In the research that my students carry out for their project work, there are three dominant themes. The first is to look into the ebbs and flows of the practices of daily life, as seen in Mark Rist's re-imagination of a culturally hybrid new type of terraced housing for Soho in London, or Yoonjin Kim's apple orchard and cider plant near Goodge Street, which would feed into a new farming cooperative headquarters in Limehouse. Second is to explore innovative energy-saving environmental design, such as the vertical hydro-powered

turbine that Yoonjin imagined could power her headquarters building, or another variant of water turbine that Jack Sardeson prototyped for the culverted River Fleet in Farringdon, designed around the properties of a Basking shark's mouth. The third theme is to embrace the role of people's subjective emotions, as in the sun-funnelled light within an underground workers' bank designed by Sam Coulton in the City of London, or the shimmering park of illusions by Katja Hasenauer near to Old Street.

The above students are from Years 3-5, but the principle of introducing students to design research can also bear fruit even earlier in the educational cycle. A current Year 2 student in my unit, Peter Davies, who in what is after all only his first term after First Year, has produced an amazingly exacting sequence of studies to explore the latent 'softness' that can be found in the Brutalist architecture at Alexandra Road and the Barbican through the analysis of colour spectrums and reflectivity. None of this line of investigation was stipulated in the unit brief, but is Peter's own explorations of this year's theme of softness in the city. What this will do, hopefully, is to push this approach further in Peter's education, as well as other students, which they can then develop over in their career to reinforce the sheer range of research and innovation created by architects.

What, however, I think needs to be added more into the mix is a closer link to political and social intentionality, to give a real driver for the pursuit of design research in architecture. I have tried in my own ways to achieve that goal. Along with my colleagues Yara Sharif and Nasser Golzari, who with me constitute the Palestine Regeneration Team, we use a research-led approach in our design consultancy for the rebuilding of disused historical towns in the West Bank. Here our explicit aim is to use architectural and urban interventions to offer opportunity and hope to a Palestinian population overwhelmed by the imposition of Israeli military power, as a deliberate means of giving architecture some genuine traction. Yet this is only to look back to a formidable predecessor, Cedric Price, whose archives in the Canadian Centre for Architecture reveal the astonishing spectrum of research undertaken for his projects, itself as an extension of the promotion of cybernetics and other trendy ideas in his AA teaching. This expansive research approach was applied not simply for the better known Fun Palace and Potteries Think-Belt, but also schemes like the Interaction Centre in Kentish Town and the Snowdon Aviary in London Zoo. Price's work sits very much in the pioneering stage of design research, with lateral thinking and processes of investigation being treated as important as, if not more important than, actual proposals for new buildings.

Today, the development of a richer and subtler approach to design research in architecture is, I would argue, the most vital contribution that our current generation of educators can make to architectural education. The advent and gradual acceptance of the approach known as design research over the past two decades has offered the first genuine opportunity to create not only research-based architectural education, but also research-based practice. By fully accepting the broad church covered by design research, and by discussing how the approach can be embedded into the educational process for forthcoming generations of young architects, the opportunities for the future become obvious. I repeat that this is an argument to be developed not only on the usual aesthetic and pedagogic grounds, but also in relation to the general role and status of architects in political and economic terms. It will therefore stand the AAE and British schools of architecture in very good stead if they now use their collective resources to acknowledge, celebrate, and develop the innovation represented by design research in architectural education.

Collective agency: the architectural collective as an emerging model for education and practice in Brazil and the UK

Jane Hall

Royal College of Art, London, UK

INTRODUCTION

This paper introduces the work of student architecture collectives in Brazil as emblematic of a new culture of design practice emerging in Latin America. Student collectives work in a liminal space between education and professional practice. Their proliferation and development of innovative design practices raises questions about the architectural design process and the professional role of the architect. By analysing the contextual factors that have led to the formation of collectively organised student groups, the reasons for their formation will be revealed. Comparison of the nascent yet prolific work of collectives amongst student architects touches on issues around authorship, collaboration, and participation while considering why working collectively lends itself to furthering their interests. This paper looks at the educational setting in which student work is produced compared with the professional constraints that students encounter on graduation.

COLLECTIVE PRACTICE AS AN ALTERNATIVE PRACTICE

While architects recognise that architectural production does not happen in isolation, working collectively is rarely acknowledged or seen as crucial to design thinking and the underlying core structure of the profession. The image of the sole author, the genius architect, has only increased its dominance, with architectural education and practice complicit in their support of singular autonomy (Schneider & Till, 2009). Beatriz Colomina has written extensively to dispel this myth, encouraging a shift away from “architect as a single figure, and the building as an object, to architecture as collaboration” focusing on close existing professional relationships between architects and their consultants, clients and more recently building users and the general public (Colomina, 2000). This has resonated amongst a generation of younger practitioners who are pushing these ideas further in practice by foregrounding collective action between architects within their own design studio. By radically disrupting hierarchical office structures, the contemporary collective demonstrates other possibilities for alternative forms of practice that confront the prevalent, understanding of how architecture is produced.

Alternative architectural practice refers to both design processes and organisational structures that challenge traditional hierarchies in

architecture. This has become an expanded field where architects are involved in a multitude of activities including writing, teaching, theory and construction to challenge the “regulated space of architecture” (Wigglesworth, 1996). Working collectively has become a prominent tenet of alternative practice, used in part as an organisational structure in order to support the exploration of alternative design techniques.

Collective practice has become part of this dialogue in two distinct ways. The first idea of the collective is to reconfigure the role of the architect in relation to the rest of society. In this respect, working collectively is seen as a way of engaging diverse groups of people in the production of the built environment, subverting the notion of architecture as a singular professional practice. The second concept of collective practice concerns the relationship between architects within their own office where design thinking and decision-making is distributed democratically despite differences in professional experience. By innovating new organisational structures for practice, architects are raising questions of authorship and in turn the control of the narrative that produces design. However they also attempt to acknowledge the benefits of exploiting individual knowledge and skill recognising the “sum being greater than its parts” (Vaughan, 2012).

While both concepts are identifiable in the emerging literature on alternative practice, there is little investigation of how groups are choosing to utilise the term collective in their practice. Vaughan uses historic precedents to define the collective as “people with some form of shared circumstances and intent” coming together (Vaughan, 2012). However, she also interchanges the words “collective”, “collaboration”, “cooperation” and “community”, the conflation of which reflects that there is not currently sufficient understanding of the contemporary collective to elucidate the rise and breadth of practitioners who identify their practice in this way.

THEORY OF COLLECTIVE PRACTICE

The contemporary collective has parallels with groups that emerged from within avant-garde artistic and architectural communities in the early to mid twentieth century, who advanced this nomenclature, borrowing their “chosen language” from subversive politics “with its rhetoric of moral urgency” (Ray, 2007). In this way the term collective is politically charged. It is intimated that by using such a label one chooses to align practice with a specific agenda rooted in social, economic or even cultural change (Ray, 2012). Therefore theoretical notions of the collective are reflected in and influenced by political and cultural critical theory. Jeremy Till notes this has long been the case, pointing to the way the word has been implemented to denote a number of positions from the “social, explicitly political, feminist, participatory, [...] bottom up, non-hierarchical and/or cooperative” (Schneider & Till, 2008). Hardt and Negri’s term the “multitude” is useful here as it builds on ideas of who may form part of the collective, conceptualising the group as one that “produces the common” rather than is united by something in common as Till suggests. Here individuality is predicated rather than subsumed. This offers a more complex reading of the idea of the collective as groups which produce meaning and consensus as an on-going process rather than unite around a predetermined manifesto, constantly affected by external influences outside of the collective (Hardt & Negri, 2004).

This notion relates closely to the term “network” which was frequently used by mid twentieth-century theorists to combine ideas affecting architecture from outside the profession with its production. This includes Umberto Eco’s work the *Opera Aperta* (The Open Work, 1962) which was influential on early identifications of multiplicity and plurality in art, architecture and other forms of cultural production (McQuire, 2016).

While Eco's writing explicitly relates to aesthetics and the valuation of an "open" art-work, where layers of meaning can be endlessly interpreted by the viewer, it has implications on the understanding of the artist in the production of the work itself. This parallels the application of Bruno Latour's *Actor Network Theory* to architectural practice, where all factors that contribute to the construction of the built environment mutually constitute each other rather than exist as separate entities (Farias & Bender, 2011) making the practice of architecture part of "socially embedded networks" (Schneider & Till, first accessed 07.01.2016). By constructing ideas of collective practice around sociological and cultural texts, there is a shift in understanding about what role the architect plays in the authorship of wider society. The introduction of multiple equitable 'authors' and the terms in which they are able to operate thus becomes a central concern.

ARCHITECTURAL COLLECTIVES IN THE UK

The contemporary intersection of critical theory with practice echoes the effect the Humanist writing of Rudolph Wittkower had on architects newly in practice in what became the post-war Modern Movement in the UK (Borra, 2014). Groups such as Team 10 promoted a shared international discourse, albeit based on the more authoritarian framework of the *Congrès internationaux d'architecture moderne* (CIAM). Members Alison and Peter Smithson became famed for their collaboration with avant-garde artists and alignment with The Independent Group founded at the ICA in 1953. Their Mat-building projects have been described as the "ultimate in anonymity in architecture" linking their work and that of their generation with an interest in the new social sciences (Domingo Calabuig, Castellanos Gomez, Abalos Ramos, 2013).

During the 1970s The New Architecture Movement was established in the UK from which The Feminist Design Collective was founded. MATRIX Feminist Collective diverged from both these groups by integrating specific aspects of theory with practice in order to seek better social relations within a developing feminist framework (Dwyer & Thorne, 2007). Collective practice in the late twentieth century thus became part of an alignment with political action relating to Marx's assertion of the potential of the collective as an alternative form of capitalist production, where workers control the profits of their own labour. In this same way architects sought a greater connection to their work in order to better control the forms of power evident in its production. These groups have had a great influence on other collectives such as Taking Place and Spatial Practice Collective despite not being more widely known by a younger generation of architects.

More recently, actual examples of collective organisation in architectural practice have not emerged in the UK in any significant number. This is despite the renewed discourse concerning alternative practice and the collective that has emerged from "under the radar" (Schneider & Till, 2008). Edwin Heathcote, writing in the Financial Times recently asked, "when the authority and influence of architects are being eroded... are such collectives the future of progressive architecture?" highlighting the work of a number of collectives including Raumlabor (Germany), EXYZT (France) and Rural Studio (USA) (Heathcote, 2015). However Heathcote's only UK example is Assemble, the architecture collective who recently won the prestigious Turner Prize, which controversially recognised the collective's cross-disciplinary approach.

ARCHITECTURAL ACTIVISM IN LATIN AMERICA

The international collection of collectives mentioned in Heathcote's article demonstrates that there is an enthusiasm for progressive alternative forms of practice, indicating the

collective model as important for subverting the understanding of the architect as a professional in a global context. One place where this has become most evident is in Latin America where the alternative practices of Alejandro Aravena (Chile), Teddy Cruz (Mexico/USA) and Urban Think Tank (Venezuela) have had a profound influence on conversations in the UK and Europe. Their reputations are based on how they address architectural processes across a spectrum of production from urban policy to self-build. While their work has been described as 'activism' rather than directly related to collective practice within their own studios, it has been linked closely with ideas of co-design and new forms of collaboration (McGuirk, 2014).

In Brazil in particular there has been a critical re-appraisal of collective practices in architecture given the fetishisation in the western media of favelas as indicative of community-led design and build. Surprisingly this discourse is being led in part by the growing number of student collectives that are working in most major Brazilian cities today. Some of the collectives are informally organised within universities working in an ad hoc manner that is more experimental than directed, while others are attempting to retain their collective structure within the constraints of industry. What is interesting is that many of them are not actually aware of each other's practice having developed their work out of localised and independent ambitions. There is therefore not yet a coherent collective movement (of collective process) despite the scale at which it is being observed. What is significant about these groups is their shared interest in foregrounding the importance of a non-hierarchical studio structure, regardless of whether their practice also contends with social and political issues topical in contemporary professional wide discourse.

THE STUDENT COLLECTIVE IN BRAZIL

This paper covers four student architecture collectives active in cities across Brazil. They are: Mícropolis (Belo Horizonte), MUDA (São Paulo), 23 Degrees Sul (São Paulo) and ENTRE (Rio de Janeiro). Each was chosen as an example because of the range of work they have undertaken and the new forms of practice they are testing. The author conducted interviews with these groups in November 2013 and again in August 2015. The interviews explore the range of motivations for working collectively, the outcomes and impact of their activity, and implications for alternative paradigms in wider architectural practice.

Of particular interest is the dichotomy between education and professional practice. Why have educational settings become the locus of collective practice in Brazil? What are the ambitions of the student collective? And how does their design thinking translate in professional practice?

THE COLLECTIVE AND EDUCATION

Architecture schools in Brazil are complex settings for learning due to the contradictory nature of their hierarchical institutional structure, which sits in contrast to the inheritance of a pedagogic legacy rooted in architecture as a tool for democratic social change. This goes back to the foundation of the Paulista School by Villanova Artigas at FAU-USP in the 1960s, which became a site of political resistance to the military dictatorship from 1964-1984 (Leon, 2014). In defiance of authoritarian rule but somehow mirroring it, Artigas introduced a dictatorial and polemical teaching approach, which has been the model for architectural education across the country ever since. What is confusing about architectural education in Brazil then is that it promotes a vision of the architect as auteur yet at the same time teaches students a Modernist history evolved from radical socialist politics. This has led the architect Milton Braga to state, "Students are always thinking

about the city and so they have to consider the collective. This is our tradition – the social tradition of the Paulista School” (Braga as quoted in Barac, 2012) yet students are actively looking outside the university for new models of education that organise these progressive ideas in a democratic non-hierarchical setting.

Resistance to the idea of the autonomous architect can be seen in the work of the collectives MUDA (Change) based at the Escola da Cidade (School of the City) in São Paulo and the collective Mícropolis from UFMG (Universidade Federal de Minas Gerais) in Belo Horizonte. Marcella Arruda, a member of MUDA, positions their work as a process where “space is not only made by drawing... but also this dynamic that characterises the space. How can we think about a project being appropriated by the people and built by the people?” (Interview D, 2013) while Mícropolis’ Vitor Lagoeiro highlights the inadequacy felt about their education, describing it as a “frustration with what most people see as architecture or urban transformation...[which] made us want to get out of it and see what we could do even though we weren’t graduated yet” (Interview C, 2013).

Student collectives have a strong desire to construct objects in the real world, extending learning through doing and making. Working together enables this despite their individual lack of professional knowledge. Mícropolis is a core group of six students who together have directed a number of small-scale design and build projects. They frame the collective in educational terms as a form of research whereby they share skill sets to engender a greater understanding amongst the group as a whole. The lack of a client and the intentionally exploratory nature of their work means that Mícropolis have mainly used ephemeral temporary installations that could better be described as events, to engage the public as a way of shaping their own design thinking. Projects included ‘*Quintal Elektronik*’, an experimental occupation of a street initiated by Mícropolis in the centre of downtown Belo Horizonte where a big party was held to encourage people to consider alternative ideas about the use of the public realm (Interview C, 2013). Public space has become widely contested in Brazilian cities with local government restricting their occupation and use. Mícropolis actively engaged in this dialogue, facilitating a wider conversation with the general public in a way that their educational setting would only allow them to experience in the abstract.

Low-fi interventions have thus come to characterise the work of student collectives demonstrating a dual wish to understand the social and political dimensions of architecture applied to realistic situations while in tandem learning how to direct public engagement, construct projects on site and direct the final work’s occupation and use.

MUDA have pushed this idea further by actually living in an *Occupação* in the Republica area of downtown São Paulo. In an illegal settlement in a long disused building on Rua Marconi, the group lived with residents joining in with their everyday activities and attempts to organise a viable community. The collective’s ambitions were to help build things for the residents, lending their design expertise, but also to offer activities and events to show the surrounding public the legitimacy of the building and its occupancy. In this way MUDA go beyond their architectural training to radically rethink how their role as architectural thinkers and designers can affect a fragile community threatened by private and political parties. The collective do not position this as an architectural project but one that allows them greater access to parts of society that they are discouraged or excluded from not least by their education, despite their belief that it is these particular communities who are most in need of architectural services. Again this example reveals both collectives’ shared interest in supplementing their university education through exposure, to the lives

of the people for whom they believe they should be designing. While collectives are using live projects as a way of gaining hands-on knowledge about the application of their professional knowledge, they are also questioning who architectural design is for.

Coining the phrase “*Aesthetics of the Possible*”, Arruda describes the approach to design that the collective has learned from the *Occupação* is to “start with what you have and do the best with what you have” (Interview D). This is the complete antithesis of what students study at university, where the topics of “practice, theory, technology and design” (Interview C, 2013) are taught abstractly and separately with little concern for real world constraints. Members of MUDA and Mícropolis are conscious that once in professional practice they will be expected to apply their academic knowledge to design projects, without the understanding of the complexities encountered in the actual design process. Arruda describes this as ignoring “the underlying layers of existence” (Interview D, 2013).

Working collectively is not an alien practice to the students. They are expected to work in groups in the design studio throughout their university training. The eventuality of having to work alone on their final major projects in their fifth year is therefore problematic to many. Mícropolis are the first group of students at UFMG to insist that at the end of the academic year their final major project would be examined collectively. In this way their collaborative process became part of the terms in which their work was evaluated. The collective thus breached the “taboo” of the design studio (Salama & Wilkinson, 2007) by asking the examiners to consider not just what is produced by the student, but also what is learnt, a shift John Habraken outlines as a key change central to the reform of teaching practices (Habraken, 2006).

Students have formed collectives initially to supplement what they’re taught with the purpose of gaining experience and learning how to apply their skill set in traditional forms of practice. However in doing so they are developing a series of additional and alternative skills that radically change their view of the profession. This has led to their desire to bridge the discrepancy between architecture as a socially motivated and holistic practice and its teaching by scientific and quantitative means. In this sense the student collective did not evolve in direct opposition to either education itself, or professional forms of practice. Rather collectives seek to enrich their understanding of both. However, this has brought a greater awareness of the architectural student’s agency in the production of architecture, encouraged by the feeling of ownership that the act of making has on a work. A reflection on the success of their initial projects has also allowed collectives to consider how their methods might reach beyond the educational setting in wider professional practice.

PROFESSIONAL PRACTICE AND THE COLLECTIVE

The role of the architect and the sustainability of collectives as a viable model for architectural practice is a question student collectives are beginning to address as their work gathers greater external interest but also as they graduate from university. Shifting from an educational setting to professional practice and buoyed by early successes, newly qualified architects are examining whether their training can be used to challenge the norms of professional behaviour. Mícropolis’ Mateus Lara sees it as likely that there will need to be a change in how they organise themselves, stating that “If we choose it as a full practice I think we might need to get more conventional kinds of projects”, although he expands upon this noting that traditional types of work are “something we would like to do as well” (Interview C, 2013). Lara demonstrates that working collectively in the university had a particular purpose that may not translate into practice. However having established a reputation before graduation, the collective has greater agency to decide the terms in

which they want to engage with traditional forms of practice.

The architecture office 23 Degrees Sul, based in Vila Madalena in São Paulo shows how a collective organisational structure can be sophisticatedly developed to maintain the ideology and agency of the group in parallel with recognising aspects of professional practice. Their studio is organised so that all involved are encouraged to partake equally. Luis Pompeo Martins, a founding member of the collective states that this allows “everyone [to...] feel they make part of the process, that they look at the final result and they see at least a bit of themselves in it” (Interview A, 2015). While there are some defined roles within the group such as project leads, these positions are interchangeable and are swapped as new work comes in. The members then do as much as they can to organise a project within a flat structure to ensure that the collective philosophy extends across partners, trainees and junior architects. 23 Degrees Sul have also found that by operating under the collective label they can extend their practice beyond architectural design projects in what Pompeo Martins calls “diffuse contribution” (Interview A, 2015). Here he refers to the research each member is encouraged to undertake to enrich the wider practice, allowing the exchange of ideas “outside of design constraints [which] is also important for further projects and initiatives”. The group plans to extend their voice within professional discourse by establishing a series of free courses on urbanism that engage the public with issues affecting the city (Interview A, 2015).

The architectural collective ENTRE is made up of a number of individuals who run their own practices yet work together as ENTRE to do additional projects that extend their architectural thinking. Based in Rio de Janeiro their early work comprised of interviews between students and practitioners. Their first publication, *Entre - Entrevistas com Arquitetos por Estudantes de Arquitetura* (Between – Interviews with Architects for Students of Architecture) was initiated because as Mariana Meneguetti from the collective states, “we felt there was a gap in our university between the students and the professionals, the academic experience and professional life” (Interview B, 2013). The collective prepare by reading theoretical texts then come together to plan a set of agreed questions before conducting the interview. The success of this action led them to expand their interview base, asking philosophers and entrepreneurs to also take part so as to “start to think beyond architecture” (Interview B, 2013). Their focus has shifted to consider public space and the construction of the city as their central issue as it “joins all the questions, we don’t just need architecture to think about cities” (Interview B, 2013). ENTRE have organised talks and workshops specifically to engage the general public to create new methods of communication between trained professionals and those with amateur interests.

What is striking is that both 23 Degrees Sul and ENTRE focus on foregrounding research as a part of their practice. They have found ways to continue learning through creating platforms by which ideas can be shared both within the collective and in dialogue with the wider profession and the public. A tenet of working collectively in professional practice for these emerging groups therefore is the ability to further design thinking by making space for research which in some way mirrors their university setting.

CONCLUSIONS

Brazilian student architecture collectives have developed innovative design methods, using their educational environment as a testing ground and microcosm for developing alternative architectural processes that may have application in wider professional practice. This paper identified two concepts that are driving the work of collectives today: the role of the architect in relation to society as part of a professional service and the

attempt to restructure practice to encourage the sharing of knowledge in a democratic setting. In both cases the ambition is to reconfigure power relationships that dispel the notion of the architect as a single arbiter of professional knowledge, which separates them from the physical production of work.

In Brazil the recent formation of a number of student collectives across the country is indicative of a younger generation intent on testing both these concepts. While all of the collectives were formed out of a reaction to deficits in their university education, which separates theoretical ideas from actual practice, their instinct to work collectively comes as a visceral rather than cerebral attempt to consolidate their learning in practice.

What has been observed is that the collective structure establishes a democratic setting that encourages individuals to contribute their personal interests to broaden and enrich conversations. This supports a culture of extended curiosity and learning that is lost after graduation. We can therefore see that collectives are using a new form of structure to change relations between one another that replicate some of the freedoms of being a student. Continued learning, flexibility, shared risk and dialogue are some of the attributes which collectives are integrating as part of their design process in practice rather than using the model to do radically different types of work.

EXPERIMENTATION

Collectives supplement their formal training by developing experimental methodologies to test ideas linking architectural theory to projects subject to actual social and economic constraints. Through limited means, collectives established effective proposals that extended their notion of architecture beyond that of a design problem. This has had repercussions on how they have come to view the role of the architect in relation to wider society. Through group discussion and analysis of the outcomes of their projects, all four of the collectives described have begun more formally structured projects that attempt to demonstrate how architects can have an alternative voice in the construction of the built environment. What is radical is that in doing so they actually show that collective structures allow a multiplicity of practice, opening the field up to a number of different types of work not restricted to the production of buildings. Through books, magazines, lectures, exhibitions and a book group, collectives have assimilated these types of work into their everyday practice of architectural production. For 23 Degrees Sul and Entre this is about communicating what architects do and the problems that practice faces to both professionals and the general public. They are developing the notion of the architect as a publicly visible stimulator for democratic popular planning, a mediator between the amateur and those who hold professional knowledge.

NEW CULTURE OF PRODUCTION

Architectural education largely focuses on training architects to direct a design process where the outcome is a built object. Students actively sought to co-construct projects with local communities, rather than design for or in consultation with them. This process elucidated the idea that collaboration fosters a convergence of meaning that creates an alternate culture of production. The immediacy of the relationship between the students and their user group changes the methodology; encouraging people to have greater engagement with and foster a sense of ownership over the wider project. This new culture where meaning is constructed through the group, but where each individual is given a platform to learn and expand their practice demonstrates how closer engagement with real life scenarios can become a crucial part of an alternate approach to education.

BETWEEN EDUCATION AND PRACTICE

It is not surprising that student collectives have been most successful in experimenting with collective practice. All in their early to late twenties, these architecture students have the freedom to act as they have little of the same professional or personal responsibilities of a senior architect even ten years older. Due to shifting expectations that have delayed when people expect to start a family, coupled with student debt and the difficulty in affording such things as a mortgage, students are less constrained during their twenties than they are later in life. Once qualified and entered into a specific part of practice the picture changes, as a full time job and legal responsibility becomes a serious deterrent to experimentation. Yet there is little focus on this particular moment of architectural training, when student architects have the basic knowledge and skill apply their ideas in practice however are not required to conform to any professional guidelines. This liminal space is where student architects should be encouraged to formally cultivate their own practice in terms of a 'new culture of production'. Collectives in Brazil today demonstrate that there is educational value in focusing on the co-construction of methods for collaboration within collective structures as part of their training, supporting the idea that practice itself should be considered a continual and integral form of education.

ACKNOWLEDGEMENTS

Thank you to all the collectives interviewed as part of this research.

- Mícropolis (Belo Horizonte, <http://www.micropolis.com.br/>),
- ENTRE (Rio de Janeiro, website re-launched soon)
- 23 Degrees Sul (São Paulo, <http://23sul.com.br/>)
- MUDA, (São Paulo, <https://www.facebook.com/MUDAcotivo/?pnref=about.overview>)
- GRUNA, (Salvador)
- Diane Lima founder of Criativos Dissidentes (Salvador/São Paulo)

REFERENCES

- Borra, B., 2014. 'The Architecture of Co-operation: A Project for Organizing Collective Creativity', PhD Thesis, TU Delft, Awarded 2014.
- Braga, M., as quoted in Barac, Matthew, 2012. 'Pedagogy: FAUUSP, São Paulo, Brazil', <http://www.architectural-review.com/archive/pedagogy-fauusp-so-paulo-brazil/8626997.article>
- Colomina, B., 1999/2000. 'Collaborations: The Private Life of Modern Architecture', Journal of the Society of Architectural Historians, Vol 58 No 3.
- Domingo Calabuig, D., Castellanos Gomez, R., Abalos Ramos, A., 2013. 'The Strategies of Mat-building', The Architectural Review, <http://www.architectural-review.com/rethink/viewpoints/the-strategies-of-mat-building/8651102.fullarticle>
- Dwyer, J., & Thorne, A., 2007. 'Evaluating MATRIX' in 'Altering Practices: Feminist Politics and Poetics of Space', ed. Petrescu, D., Routledge.
- Farias, I. & Bender, T., 2011. 'Urban Assemblages: How Actor Network Theory Changes Urban Studies', Routledge.
- McGuirk, J., 2014. 'Radical Cities', Verso.
- Habraken, J., 2006. 'Questions that will not Go Away: Some Remarks on Long-Term Trends in Architecture and their Impact on Architectural Education', Key not speech, Open House International.
- Hardt, M., & Negri, A., 2004. 'Multitude', The Penguin Press.
- Heathcote, E., 2015. 'Is Assemble the Future of Progressive Architecture', <http://www.ft.com/cms/s/0/0a0d7874-2ef5-11e5-91ac-a5e17d9b4cff.html>
- Interview A. with members of 23 Degrees Sul, São Paulo, August 2015
- Interview B. with members of Entre, Rio de Janeiro, November 2013

Interview C. with members of Mícropolis, Belo Horizonte, November 2013

Interview D. with members of MUDA, São Paulo, November 2013

Leon, AM., 2014. Chapter in Weizman, I., 2014. 'Architecture and the Paradox of Dissidence', Routledge.

Nussbaum, B., 2010. 'Do Gooder Design and Imperialism', <http://www.fastcodesign.com/1661894/do-gooder-design-and-imperialism-round-3-nussbaum-responds>

McQuire, S., 2016. in 'Designing Design: Cartographies of Theory and Practice', ed. Grierson, E., Edquist, H. & Richot, H.

Richter – Dahl Rocha Associés, 2014. 'Towards an Integral Practice of Architecture', Walter de Gruyter.

Salama, AMA. & Wilkinson N., 2007. 'Design Studio Pedagogy: Horizons for the Future', Architectural Design.

Schneider, T. & Till, J., 2008. 'Alternate Currents', Editorial Field Journal, Vol 2 No 1

Schneider, T. & Till, J., 2009. 'Beyond Discourse: Notes on Spatial Agency', Footprint, Delft Architecture Theory Journal, No 4.

Schneider, T. & Till, J., <http://www.spatialagency.net/>, first accessed 02.01.2016

Schneider, T. & Till, J., 2011. 'Practice: Beyond Building', Architecture Today, <http://www.architecturetoday.co.uk/?p=14196>

Simmel, G., 1971 'On Individuality and Social Forms: Selected writings [of] Georg Simmel', University of Chicago Press.

Thorpe, Ann., 2012. 'Architecture and Design Versus Consumerism: How Design Activism Confronts Growth', Routledge.

Vaughan, L., 2012. 'The Design Collective: An Approach to Practice', Cambridge Scholars Publishing.

Ray, N., 2007. 'Architecture and its Ethical Dilemmas', Taylor and Francis.

Wisnik, G. in Anelli, R., 2015. 'Lina Bo Bardi 100', Hatje Cantz.

Design prototype

Claudia Pasquero, Bartlett School of Architecture, UCL, UK

Emmanouil Zaroukas, University of East London, UK

ABSTRACT

In contemporary academic environments progressive architects and urban designers struggle to cope with the prevalent paradigm of research, which still rests on the well-established problem-solution couple. Lately, emphasis is given to ‘research by design’ that, although it accounts for the peculiarities of design as research method, it does not break with the presuppositions in the way research is pursued. In this paper we recognize the prevalence of two paradigms in research. One that starts with a well-posed research question and seeks an optimal solution and another that originates from an ill-defined problem and potentially leads to a plethora of solutions.

We argue that neither the optimal solution neither a variation of answers secures the imperative of novelty and relevancy of knowledge that can fuel practice and academia. The methods of delimitation of research by specifying the problem a priori in the form of a research question seems to be obsolete since it suggests a research that finds its innovative trope in a space of possibilities already given by the way the question is posed. In this sense design, it can be argued, is degraded to an operative medium for the exploration of that space.

In this paper we propose a different mobilisation of design in research that aims primarily but not exclusively to question the constitution of problems and to turn that question into an affirmative proposal. In order to do this, we trace a transition from variational to differential prototypes where innovation is effected by experimenting with the problematic field and not exclusively with solution space. With problematic we identify the domain through which problems are formed. Design in this case then becomes the process of designation of a problem and the production of knowledge is effected by reframing the problematic.

Without dismissing the historical formation of the disciplines of architectural and urban design, prototypes transgress traditional boundaries and categories allowing for the appropriation of and experimentation with diverse apparatuses and machines. In this sense, not only history reads differently but also problems are constituted differentially. Operating with a curiosity to access the nonhuman, those inhuman prototypes aim to penetrate disciplinary boundaries to problematize problems and to articulate artefacts with transformative agency.

“Design research” aims therefore to respond to the themes of curiosity and participation by harvesting a multitude of points of view that form an ecology of prototypes folding inhuman and human agencies. Experimenting with

biological organisms like micro-algal cultures and technological apparatuses, 'designed prototypes' become processes of designation of the problem in an inhuman way. In order to articulate the argument in more pragmatic aspects we look how the practice of ecologicStudio has designed an urban bio-digital prototype as research medium, structuring a continuous feedback between research and practice, between design brief and research question.

Within this context design research is executed by apophatic prototypes with transformative agency for an architectural discipline yet to come.

INTRODUCTION

In academic environments and professional practices progressive architects and urban designers struggle to cope with their intellectual insights and the production, evaluation and distribution of knowledge that they create in a world that tends to slip their comprehension and it challenges constantly their conventional ideas about their disciplines. Nonetheless, as Murray Fraser (2013) has recently stated in his extensive literature review on design research *"the most accepted mechanism for creating new insight and knowledge in any cultural or academic field, or of attempting to understand the past, or present or future conditions, is through research."* (Fraser, 2013) Normative definitions of research can be found in the literature but what seems to be a contemporary trend is the **sharing ethos** of insights that can be exchanged between disciplines. This is reflected by the revised definition that the Research Excellence framework provided in 2014 and defines research as *"a process of investigation leading to new insights, effectively shared"* (Fraser, 2013). The EAAE provides a more specific working definition to Design Research by describing it *"as the processes and outcomes of inquiries and investigations in which architects use the creation of projects, or broader contributions towards design thinking, as the central constituent in a process which also involves the more generalised research activities of thinking, writing, testing, verifying, debating, disseminating, performing, validating and so on"* (Fraser, 2013).

Murray Fraser (2013) mainly and Michael Hensel (2012), to a certain extent, have both provided a literature review of the development of Design Research in academia and practice, both of them supporting a close integration of the two. A closer reading of the books edited by the aforementioned authors reveals one of the issues that this paper is willing to discuss and to develop in order to reorient Design by Research in the coming years. The prevalent paradigm of Design by Research still rests on a problem-solution couple that is always formed and positioned within an anthropocentric or human-oriented framework. The problem is formulated in such a way as for architecture to serve the human. Research, in other words, is willing to address a human image directly by focusing on its social, political everydayness or indirectly, through technological development. It appears therefore that design as a methodology in architectural research, which operates in academia and practices, is being subjected to and capable of addressing only a given human image. That was and still is the ambition from the operational research tactics of the post-war period as 'design methods' or 'design science', to recent 'research by design'. In this paper we recognize the prevalence of two paradigms in research. One that starts with a well-posed research question and is seeking an optimal solution continuing the premises of 'design science' of 60s and another that originates from an ill-defined problem and potentially leads to a plethora of varied solutions. Our position therefore leaves behind the arguments revolving around 'design science', asking therefore to what extent design is science and focuses on the remark that our epistemological questions are all-too-human.

In this sense we make a decision to suggest three provisional categories: that of the human, inhuman, and nonhuman not as dogmatic categories capable to explain the rather thick reality of research but as means for their respective reconstitution or for their potential replacement by other novel materialisations. Science, in this sense, is the human inquiry that is mediated by inhuman apparatuses in order to produce knowledge about the nonhuman world. If that stands as a standard approach of science that mobilised operational research and ‘design science’ then it is also suggests science as assemblages of human and non-human agents in the sense suggested by Bruno Latour (1991). What we are missing though in those understandings is what McKenzie Wark has argued recently that *“The sciences cannot help but bear traces of a radical [inhuman] otherness, even when the human discourse that results is saturated in metaphors drawn from mere human and historical social formations”* (Wark, 2015).

To account for those traces of the radical otherness we turn to Eugene Thacker’s (2014) definition of “weird media” and the mediation of what is impossible to be mediated that affords in this sense apophatic conception of research. Weird media reveals that it is an ontological excess to the things that we encounter and not only an epistemological subtraction as Kant’s constitution of subject object would have it in relation to the thing-in-itself. Weird media are becoming apophatic in the sense that the thing-in-itself cannot be communicated but only by negating the decision to name it as such. For that matter Karen Barad’s (2007) intra-active realism becomes operative. The ontological radical other is the inhuman for Reza Negarestani’s (2014) reading of the human labour. The *apophenia* therefore as the practice to assume patterns and connections out of noisy data and to draw metaphors from them gets a positive treatment in MacKenzie Wark’s (2015) reconception of Bogdanov’s “tektology” as a new sharing ethos.

In order therefore to mobilise the above-mentioned concepts we suggest to follow Eugene Thacker (2011) and cut the world into: “for-us”, “in-itself” and “without-us”. This distinction will constitute the premises upon which we will discuss the three prototypes designed as the Ecologic Studio, as cases to reveal a new direction in research that rests on the apophatic mediation of the prototypes that spans between academia and practice. The paper will conclude that the real challenge for design research is not to be found in the epistemological part of the “world-for-us” and the “world-in-itself” but in a serious consideration for the “world-without-us”.

RESEARCH AS PROBLEM-SOLVING: THE ANTHROPOCENTRIC PREDICAMENT

Horst Rittel and Mervin Webber in their *Dilemmas in General Theory of Planning* of 1973 opposed the rigorous and clear definition of problems under Operational Research. The epistemological uncertainty becomes for Rittel and Webber the premise for a revision and rejection of the ways that operational research posed scientific problems. Rittel and Webber concluded that the incomplete knowledge of the problem or the noise or entropy that enters into a system make the articulation of a clear and well-defined problem impossible. However, the critique that they raised to Operational Research methods was still considering research as a problem-solving process within an anthropocentric framework. Their attempt therefore to incorporate uncertainty in the problem-solving couple was simply to account for uncertainty in an epistemological way. The difference between the two approaches is reflected in the difference between logical understanding of reality and meta-understanding of reality, where we adopt the definition of ‘meta’ by Gregory Bateson (2000).

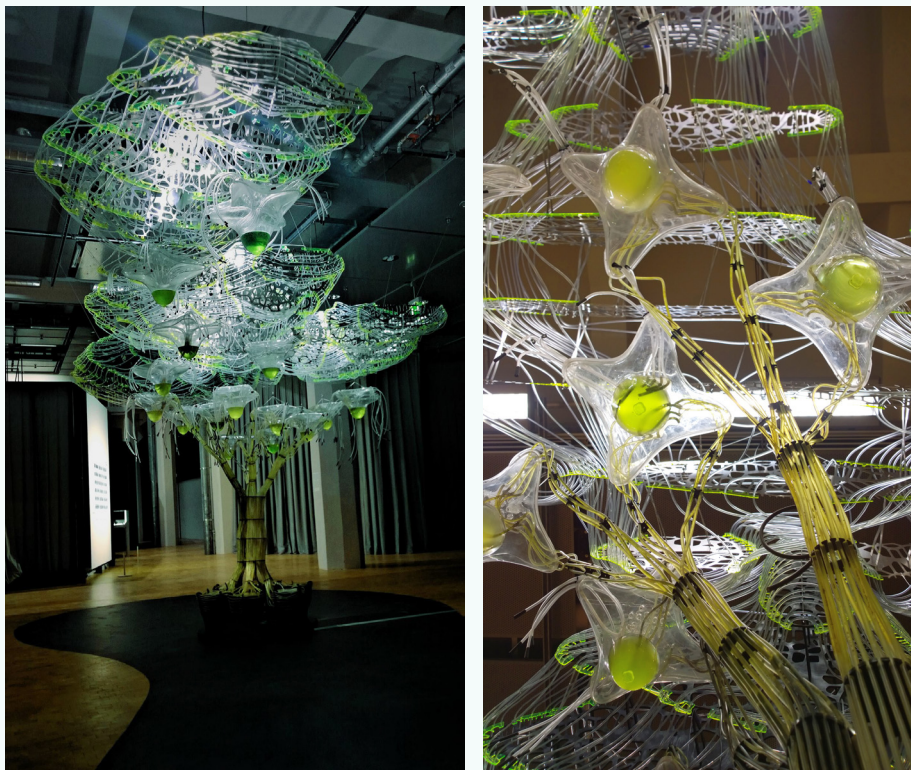
Neither the optimal solution nor a variation of answers secures the imperative of novelty

and relevancy of knowledge that can fuel practice and academia. No human being can be considered purely logical or purely creative but we all are equipped with a complex mix of skills that define our very unique understanding of reality. The methods of delimitation of research by specifying a priori the problem in the form of a research question seems to be obsolete, since it suggests a research that finds its innovative trope in a space of possibilities already given by the way the question is posed. In this sense design, it can be argued, is degraded to an operative medium for the exploration of that space. While we believe that one of the main characters of design is exactly the one of being able to bridge between logical understanding of reality and meta-understanding of reality. Rittel and Webber will frame this distinction conceptually by giving to the first instance the notion of the ‘tamed’ problem and to the second that of the ‘wicked’ problem. The wicked problem deals mainly with the uncertain and as such it is impossible to frame and define it clearly. The epistemic uncertainty of the wicked problems refers either to the incomplete knowledge of a well-defined system, or to noise and randomness that ingress into the system and therefore make impossible any prediction in advance of the course of the system under question. Rittel and Webber’s attempt therefore to incorporate uncertainty into problem-solving was to simply account for uncertainty in epistemological way.

The world becomes increasingly difficult to comprehend. For this reason Eugene Thacker (2011) in *In the Dust of this Planet* attempts to slice the world into three categories in order for him to account for what emerges as an unthinkable world. The relevance to research and to design research in particular is of great importance since it is our embeddedness in the world through which we understand it and we produce knowledge of it. The “world-for-us” therefore is our world. It is the human world that we inhabit, interact, interpret and give meaning to it. It is the world that, as Thacker observes “we are at once a part of and that is also separate from the human” (Thacker, 2011). The world-for-us is not so compliant though as we would like to think. It “bites back”, it “resists, or ignores our attempts to model it into the “world-for-us” (Thacker, 2011). This is the world that has an agency and therefore an autonomy and it is the “world-in-itself”. The world-in-itself is however a paradoxical conception. By the moment we think of it and we act upon it then it is transformed in to the “world-for-us”. “A significant part of this paradoxical world-in-itself is grounded by scientific inquiry – both the production of scientific knowledge of the world and the technical means of acting on and intervening in the world” (Thacker, 2011). Rittel and Webber’s discussion on the tamed and wicked problems is therefore situated within this reciprocal and paradoxical understanding of the world-for-us and the world-in-itself. The impossibility therefore to create a mirror between the world-for-us and the world-in-itself is due to the epistemological uncertainty that is a result either of human beings’ cognitive limitations or due to noise and randomness in the data abstracted. The bounds of our intelligibility and the incomprehensible world haven’t stopped humans thinking speculatively beyond the limits that define us as human beings, this “spectral and speculative world is the world-without-us” (Thacker, 2011). It is only through speculation that we can create metaphors for this world. The world-without-us does not need to have as horizon the extinction of the human. It is the subtraction of the human from the world that is the world-without-us. In these three different conceptions of the world we are glimpsing the possibility of breaking the circle that the correlationist Kantian doctrine (Meillasoux, 2008) has established in epistemology and to inquire into an ontology beyond the phenomenological world.

THE INHUMAN

What we therefore suggest is to reconceptualise Rittel and Webber’s discussion on research problems through an additive ontology and a subtractive yet speculative epistemology. Actual entities are first and foremost patterns of relations of other agential



interactions. However, those agents although real are plunged in to the world-without-us which is real but not actualised and therefore virtual. Philosophers like Alfred North Whitehead (1985), Gilles Deleuze (2004) and recently Manuel Delanda (2011) and Karen Barad (2007) have explored the ontological indeterminacy of the world-without-us by constructing respectively different speculative schemes. It is first and foremost that ontological indeterminacy that makes the constitution of the problem not only difficult, but mostly speculative. Rittel and Weber have clearly stated: *“the most intractable problems is that of defining problems”* (Rittel and Webber, 1973). Instead of trying to build on the Kantian limitations of correlative subject and object, that is on epistemological limitations like Rittel and Webber do, the genealogy of the thinkers that we have mentioned argue for an additive ontology, a surplus value that intervenes and problematizes the problem in its resolution.

The intra-active realism of Karen Barad would allow us to discuss an excessive and contingent ontology of things. Karen Barad, a quantum physicist turned philosopher, has argued about the role of quantum indeterminacy on an ontological level, a critique on the Cartesian narrative of substances and discreteness but also a critique on the importance on mere and given agential relations. With the concept of intra-actions and her agential realism that she has developed in her book, *Meeting the Universe Halfway*, Barad opens up the question of knowledge-production beyond the correlationist epistemological trend of the world-for-us and the world-in-itself that underlies most of the current research. The explicit and implicit hierarchical anthropocentrism of design research restricts the formation of problems to a set that corresponds to a general conception in which architecture serves the human. ‘Human’, in these two instances is recognised as a given

category (either as social-political or affective-parametric) that design and/or technology is obliged to address. Barad's intra-active paradigm meshes the interactions of human and nonhuman agencies into apparatuses. An inhuman, alien, revisionary and constructive force inherent in those apparatuses cuts the world differently into novel materialisations and conceptual categories of the human and non-human that are more fictional and speculative than given and dogmatic.

It is in this sense, however, that philosopher Reza Negarestani tries to rescue this horizontality from the anti-humanist impulses by suggesting a reciprocal presupposition between the inhuman and the human, "*the truth of human significance -...- is rigorously inhuman*" (Negarestani, 2014). Negarestani suggests therefore a verticalism that reinstates humans' rationality and capacity for abstraction and sees the inhuman as the spark for a revisionary and constructive intervention. The task at hand for design research is therefore not a user-oriented design research, but a design-oriented user even if that user is a heterostatic assemblage of nonhuman and human entities, that they do form apparatuses capable of recutting the world differently. It is in this sense that the call for design research of the future parts from the traditional distinction between the tamed and wicked problems, the invocation of the interdisciplinary and the call for participation and increased curiosity. Our position is that all the aforementioned, although still relevant, rests explicitly and/or implicitly on a hierarchical anthropocentrism; the 'world-for-us', the 'world-in-itself'. The question therefore that our prototypes construct is to address the planet as 'world-without-us'. In this sense the prototypes call to rethink research participation and curiosity in a non-hierarchical human-oriented world by allowing the world-without-us to refract the sensible and to recut categories creating new metaphors.

McKenzie Wark(2015) in his recent book *Molecular Red: Theory for the Anthropocene* reconstructs Alexander Bogdanov's concept of "tektology" in an attempt to stress the speculative approach to science, science as the practice of opening views out of the guarded world of humanities discourse.

Tektology therefore is:

"... neither a theory nor a science, tektology is a practice which generalises the act of substitution by which one thing is understood metaphorically via another. It is a practice of making worldviews... the wager of tektology is that it might be possible to construct a kind of low theory whose purpose is to experimentally apply understandings of one process to other quite different processes to see if they can be grasped as analogous. It is a kind of detournement that works sideways, from field to field, rather from past to present" (Wark, 2014).

A tektological orientation, therefore, will allow us to share metaphors that emerge out of our prototypical interventions with the ambition of resonating with other efforts and to scale them up in a planetary scale, which is the domain of real change. Tektology, therefore, is about sharing, not methods and tools but new metaphors.

DESIGN PROTOTYPE

//STEM//

The first of the bio-digital series we are investigating as case studies in this paper was proposed for the London Architectural Biennale 2006 and subsequently was presented in the Italian Pavilion at the Venice Architectural Biennale 2006. This first prototype responded to an interest to work with urban air pollution in a way that would avoid a direct solution



▲ ► STEMcloud

of a well-posed problem. It would look at urban prototypes, which at the time we called *ecoMachines*, which would be on one side able to re- describe spatially and materially the architecture of our cities and at the same time reprocess some of its pollutant in an explicit manner. STEM v1.0 in particular was using micro and macro-algae from the local ponds and rivers, which were considered a problem for the local ecology and allowing them to grow into recycled hospital bottles organized in a honeycomb geometry. Architecturally, STEM v1.0 was presented as a living screen able to engage with sunlight and air pollution to generate oxygen via photosynthesis. In terms of its infrastructure, STEM v1.0 proposed a 'transparent system' where the capability of the screen to absorb carbon dioxide is directly reflected in the number of oxygen bubbles produced and in the longer term, in the density of macro and micro-algae present in the system itself.

STEMv1.0 continuously evolves its physical qualities; light is filtered and captured for photosynthesis, oxygen is produced and carbon dioxide adsorbed; the more the light, the more the carbon dioxide, the more oxygen production, as well as density of algal growth, which will in turn increase the screening potential of STEM itself; less light and less carbon dioxide on the contrary will correspond with less growth and more transparency.

The overall systems configuration, its liquid transparency and its breathing potential is initially defined by the radiation gradients in the space; but as the living material starts to grow and evolve, the parameters will influence each other and the system will be subjected to constant transformation and will demand artificial manipulation, or interaction, from the users.

Rather than looking at solving the problem of pollution we looked at an architectural structure that would be able to absorb pollution as part the dynamic system that defines its existence.

//STEMcloud//

The STEMcloud v2.0 series presented at the Venice Architectural Biennale 2008 and to the Seville Art and Architectural Biennale 2008, evolves the morphological aspects of STEMv0.1 as well as human/inhuman interaction – the project proposes the development and testing of an architectural prototype operating as an oxygen-making machine.

STEMcloud v2.0 operates as a breeding ground for micro-ecologies found in the local water bodies such as the river of Seville, the Guadalquivir or the Venice Lagoon, while at

the same time involving the public in the breeding process. The transparency and porosity of the architectural system allows the process to be visually and materially exposed to and interfaced with the microclimate of the gallery; while STEMv1.0 present itself as an almost autonomous machine where the evolution of the system is a result of a continuous feedback machine/environment, in the case of STEMcloudv.20 the public will act as a perturbation as well as involuntary gardener of the system at the same time, by feeding the micro-algal colonies from the local river water with nutrients, light and CO₂ and as a result oxygenating the gallery space. The growth process will be triggered by patterns of interaction with the public and in turn will affect these patterns with its visual effects. Multiple feedback cycles are provoked within the components of the system, with the gallery environment and within the city itself.

This extended model of systemic architecture can be understood in cybernetic terms as a multilayer crossing of feedback loops. Cybernetics provides an operational framework to deal with change and transformation, the two main defining qualities of our new ecological understanding of architecture; the starting point of the experiment is artificially defined by us and provides what scientist call a primed condition necessary to promote interaction.

The basic cybernetic set for the Seville experiment includes 3 components: the urban environments (the river ecology and the gallery space), the architectural machine (STEMcloud) and human behavior (the visitors). These systems are multilayered and diverse and they will interact in a variety of ways: in this sense we can consider the experiment as complex, the outcome of it unpredictable and the question is 'wicked'. It is impossible to tell what kind of equilibrium will emerge within each of the 3 systems; what kind of algae ecologies will grow? How will visitors be reacting to them?

In the impossibility of control, the experiment is about communication: STEMcloud is organized to allow and promote communication among the systems in such a way that a conversation/learning process could emerge. Visitors will be transformed in ecologists, the STEM blocks into microhabitats, the gallery into an oxygenating garden or, perhaps, laboratory. The priming of the system and the channels of communication between systems have been carefully designed and engineered and can be summarized as a series of feedback loops within the more generic cybernetic set previously described.

// HORTUS London 2011 – Paris 2012// intra-action

The etymology of the word garden comes from the German *Garten*, the original meaning of which is enclosed or bounded space, in Latin *hortus conclusus*. H.O.R.T.U.S. engages the notions of urban renewable energy and agriculture through a new gardening prototype; the proto-garden hosts micro and macro-algal organisms as well as bioluminescent bacteria; fitted with ambient light-sensing technologies and a custom-designed virtual interface, H.O.R.T.U.S. stimulates the emergence of novel material practices and related spatial narratives.

Flows of Energy (light radiation), Matter (biomass, CO₂) and information (images, tweets, stats) are triggered during the four weeks long growing period, inducing multiple mechanisms of self-regulation and evolving novel forms of self-organisation.

H.O.R.T.U.S. proposes an experimental 'hands-on' engagement with these notions, illustrating their potential applicability to the masterplanning of large regional landscapes and the retrofitting of industrial and rural architectural types, as exemplified in the project *Regional Algae Farm* developed by ecoLogicStudio for the Swedish region of Österlen.



▲ HORTUS



▲ ▲ HORTUS



▲ ▲ Urban Algae Folly

isitors are invited to engage daily with H.O.R.T.U.S, inventing new protocols of urban bio-gardening; the biologic diversity within H.O.R.T.U.S is provided by local lakes and ponds; as algal organisms require CO₂ to grow, visitors are invited to contribute by blowing air inside the various containers (photo-bioreactors), as well as adjust their nutrients' content; oxygen is released as a result, feeding the other organisms in the 'briccole' (bioluminescent bacteria) and in the room.

Information flowing daily through H.O.R.T.U.S feeds its emergent virtual garden, accessible via smart phones; its virtual plots are nurtured by the flow of observations posted by each visitor, locally and globally, by lighting levels data streams and by human interaction in real-time. Such virtual organisms offer the opportunity for capturing and sedimenting information and cultivation practices, enriching the material experience of the visitor turned urban 'cyber-gardener'.

//Urban Algae Folly Milano Expo2015 – Braga Praça De La Republica 2016//

The Urban Algae Folly is an intra-active pavilion integrating living micro-algal cultures. The shift, in this case, is from an indoor, almost domestic prototype, to an outdoor public folly. For us this is a built example of architecture's bio-digital future. Microalgae, in this instance *Spirulina* and *Chlorella*, are exceptional photosynthetic machines; they contain nutrients that are fundamental to the human body, such as minerals and vegetable proteins; microalgae also oxygenate the air and can absorb CO₂ from the urban atmosphere ten times more effectively than large trees.

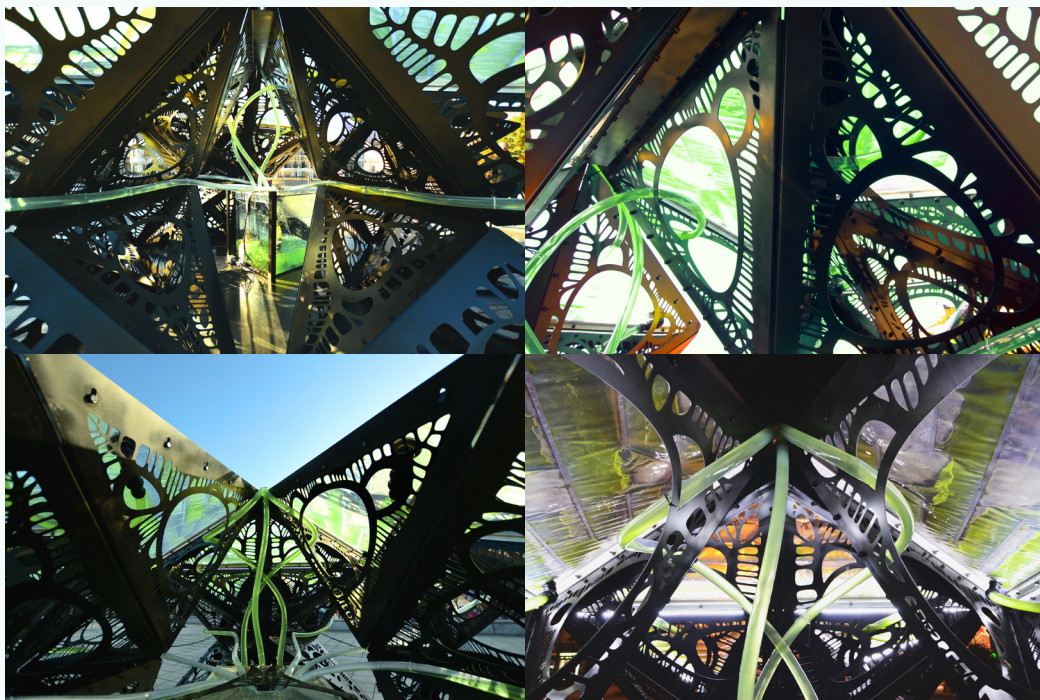
The architecture of the *Algae Folly* originates from the evolution of the well-known ETFE architectural skin system; in this instance it has the ability to provide the ideal habitat both to stimulate *Chlorella* and *Spirulina*'s growth and to allow a comfortable staying for visitors.

Visitors influence the cultivation protocol with their presence and at the same time become part of a public harvesting event where the micro-algae are collected and consumed as gourmet dishes on site. The mechanism of interaction is, in the case of these two follies, more similar to the one of the original STEM than in it is to one of the later H.O.R.T.U.S series, in fact the architectural appearance and shading potential of the folly emerge from the interaction between the human/folly/environment: on sunny summer days the microalgae will grow rapidly thus increasing the shading potential of the architectural skin providing shading for diverse activities; visitors, with their presence, will in turn activate the digital regulation system which will stimulate algal oxygenation, solar insolation and growth.

In any given moment in time the effective translucency, colour, reflectivity, sound and productivity of the Urban Algae Folly are the result of the symbiotic relationship of climate, microalgae, humans and digital control systems. This prototype allowed us to evolve the material system of our bio-digital algae farming prototype so to become more integrated into a dynamic architectural and urban context.

THE WEIRD PROTOTYPE

Every prototype that we have developed and presented in this paper shares the weirdness of mediation. At the core of *weird media* is the idea of "the mediation of what cannot be mediated" (Thacker, 2014). A type of communication with that which cannot be mediated can only be achieved by negation. That means negating the subject-object dichotomy or the human-nonhuman one. In this sense Thacker calls us to think the prototypes not as



devices, tools, or even objects that facilitate the communication between the world-for-us and the world-in-itself but as a form of mediation that is operative between the world-for-us and the world-without-us. At the time that mediation is negated, a pure communication results that is prior to any dichotomy. We do therefore have a communication between two orders of reality.

"This is quite different in principle from the modern view of mediation given by

cybernetics and information theory. There, one has a mediation between two points within a single, shared, consensual reality. While there may also be messages, channels, senders, and receivers, in [weird] media have one important difference: the mediation is not between two points in a single reality, but between two realities” (Thacker, 2014).

Every prototype in its operation as weird media refracts its inputs by materialising new agential entities. In this sense the prototype extends the human’s sensorium domain and therefore reconstitutes an agent that is augmented and transformed to feel more than what a human subject can. This is the promise of our prototypes when functioning as weird media.

Thus every single prototype therefore constructs an intra-active ecology on its own. The folly becomes an apparatus and as such creates a platform that folds together processes and refracts new materialisations possible to create new metaphors and speculations for inhabiting a built artefact while participating in the production, distribution and management of energy. It is not an interdisciplinary convergence and neither simply an ecology of participants. It is an intra-active field that constructs an ecology of participants. The agential capacity of the prototype therefore overcomes “[t]he usual notion of interaction” and of the participation to the extent that “assumes that there are individual independently existing entities or agents that pre-exist their acting upon one another. By contrast, the notion of ‘intra-action’ queers the familiar sense of causality (where one or more causal agents precede and produce an effect), and more generally unsettles the metaphysics of individualism.” (Barad, 2012)

In this sense the prototype brings together human and nonhuman agents organic and inorganic that “do not pre-exist as such but materialise in intra-action” (Barad, 2012). The prototype becomes an assemblage of heterostatic processes that at certain points ‘refract’ representations of the human and nonhuman and construct a world-for-us. In this sense the production of knowledge, although saturated with human metaphors and images, bears traces from the inhuman. The whole world becomes an intra-active-ecology in our view and prototypes become apparatuses through which the categories of human and nonhuman are apophatically constructed. The world-without-us therefore that looms at the shadows of the world-for-us is the inherent ontological indeterminacy or contingency that partakes in agential relations in a given moment. These experimental refracted moments therefore should be conceived of as a springboard not for an explanation but for a ‘what if’ experimentation with the given conditions.

Curiosity in these relational terms of intra-action parts away from the Kantian scheme of what is possible to be known. Curiosity is importance. Curiosity is to access and experiment with the way things form a state of affairs. Curiosity is not transparency. Transparency is rather an unfortunate term in that it implies a concrete reality beyond the epistemological limits of our species. Transparency is epistemological, curiosity is ontological. Curiosity needs the importance that rationality provides but also the sensing that affectivity suggests. It is through the bridging of the importance and the affect that curiosity acquires its full interventionist power as revisionary and constructive agent.

CONCLUSION

It is through this turn to ontology that the prototypes become alien and as such suggest a materialisation of creatures that not only overcome the traditional distinctions of nature-culture, organic-inorganic but open a new path to design research as problem making

prior to problem solving. This ontological turn allows us to rethink the role of apparatuses and media in the design process. Instead of researching the nonhuman world with inhuman apparatuses for the production of human knowledge, as research by design suggests, we turn that around and we argue for the importance of prototypes in research as weird media.

“The task of design research as it is presented is not finding a new or improved version of the world-for-us, and it is not to relentlessly pursuing the phantom objectivity of the world-in-itself. The real challenge lies in confronting this enigmatic concept of the world-without-us, and understanding why this world-without-us continues to persist in the shadows of the world-for-us and the world-in-itself” (Thacker, 2011). That is, the realisation that inquiry and knowledge cannot be addressed by architectural objects and apparatuses as discrete objects in the world-for-us. In the world-without-us their intra-actions materialise representations capable of having a transformative agency in the world-for-us.

REFERENCES

- Barad, K., 2007. Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning. Duke University Press, London.
- Bateson, G., 2000. Steps to an Ecology of Minds. The University of Chicago Press, London.
- Deleuze, G., 2004. Difference and Repetition. Continuum, London.
- Delanda, M., 2011. Philosophy and Simulation: The Emergence of Synthetic Reason. Continuum, London.
- Fraser, M., 2013. Design Research in Architecture: An overview. Ashgate, Farnham.
- Hensel, M., 2012. Design Innovation for Built Environment. Research by Design and the Renovation of Practice. Routledge, London.
- Negarestani, R., 2014. The Labor of the Inhuman. In: R. Mackay and A. Avanessian eds. #Accelerate: The Accelerationist Reader. Urbanomic, London. pp.425-466.
- Rittel, H.W, Webber, M.M., 1973. Dilemmas in General Theory of Planning. Policy Sciences 4, pp.155- 169.
- Thacker, E., 2011. In the Dust of this Planet: Horror of Philosophy vol1. Zero Books, Winchester.
- Thacker, E., 2015. Dark Media. In: A. Galloway, E. Thacker and M. Wark eds. Excommunication: Three Inquires in Media and Mediation. The University of Chicago Press, London. pp. 77-149.
- Wark, M., 2015. Molecular Red: Theory for the Anthropocene. Verso, London.
- Wark, M., 2015. Capitalocene. Public Seminar [blog] 15 October. Available at <http://www.publicseminar.org/2015/10/the-capitalocene/> [Accessed 18 January 2015].

Drawing from curiosity: The role of reflective drawing in architectural design, research and learning

Dr. Miguel Jaime, Department of Architectural Engineering,
Alhosn University, UAE

Dr. Eugenia Lopez Reus, Department of Architecture and Design,
Abu Dhabi University, UAE

ABSTRACT

When we draw, our hand does for the eye “*something that the eye, the specific organ of vision, cannot do by itself*”, says the 19th century German theorist Konrad Fiedler. In *The Reflective Practitioner*, Donald Schön calls “*virtual worlds*” the drawings that allow instructors and students to test possible solutions in the architectural design studio without too much risk. Drawing is also how architecture relates to its precedents with appropriateness, in John Hancock’s opinion. Curiosity is a common driver to all these activities as none of them are able to know their ends until their final configurations are accomplished.

Since drawing is involved in all the described processes this paper aims to study the specific *reflexiveness* of drawing in artistic production, design, learning, and research. With this purpose in mind, we review in this investigation the philosophical foundations of artistic *visuality*, the cognitive aspects of design, and the use of drawing as a historical research tool.

The pivotal notions that will guide this inquiry are the aesthetic autonomy, involved in the judgment of beauty in Immanuel Kant; *visuality* associated to drawing in Konrad Fiedler’s philosophy of art; the designer’s reflection-in-action proposed by Donald Schön as the essential characteristic of the artistry of professional practice; and, finally, the notion of historical precedents of John Hancock and Roger Clark and Michael Pause that assign to drawing the possibility of being inclusive and specific at the same time.

At the end of this paper there are enumerated a series of contemporary exaggerations of *reflexiveness*, authentic forgeries of Kantian anti-dogmatism, in this case in the ambits of political economy and politically motivated architecture, as a testimony of the fact that *reflexiveness* has been simultaneously a curse and a cure in our convulsive era.

INTRODUCTION

This paper vindicates the role of drawing as educational and research tool within architectural design process. If education is understood as learning (not teaching), a process in which the learner mobilizes all his/her intellectual, spiritual and physical resources in order to overcome the perplexity of an

unresolved question, then, both education and research have an identical vocation for dealing with the unknown. From this point of view, the differences between education and research just appear at their respective ends: education is meant to transform the student into an autonomous human being, and research to produce communicable knowledge for the advancement of the respective discipline. Research-based education, the context in which this paper should be understood, imposes that students learn from experiences that produce knowledge, and these experiences transform them into the type of citizen democratic societies aspire.

An education that involves the production of knowledge should be called reflective, as reflective education implies creativity and not the faithful transmission of pre-elaborated content. In this type of education, common curiosity and discovery are part of the inspiring atmosphere of the learning environment. Research is a constituent part of reflective education, which must be supported by verifiable methods that attend to its precise ends. This paper proposes that drawing could be one of these methods of inquiry. Even more, in the same line as German theorist Konrad Fiedler stated in the 19th century, drawing explores realms of reality and consciousness in autonomous ways that cannot be reached in any other way: *“even by drawing one line or by doing a gesture that represents something as perceived by the eye one would realize that is creating for his visual representation something that the eye, the specific organ of vision, cannot do by itself”* (Fiedler, 1887). Fiedler sustains that drawing, the basic artistic activity, accomplishes the kind of *“stability and verifiability”* (1887) for images that are only achievable by concepts through intellectual activity.

This paper investigates the role of drawing within architectural design processes. Quality of design is normally associated with drawing. Drawing is the base of experimentation that creates *“virtual worlds”* (Schön, 1987) in which different hypothesis can be tested at the design studio. Drawing is also essential in the *“reflection-in-action”* category with which American philosopher and educator Donald Schön distinguishes practice.

The notion of reflectiveness associated with drawing is the umbrella under which practice, learning, and research are studied here. Reflective means a type of intelligence that keeps an eye in its own action all the time. It is exactly the contrary of dogmatism, which was defined by 18th century German philosopher Immanuel Kant as the *“procedure of pure reason without a previous criticism of its own power”* (Kant, 1781). Ultimately, the objective of this paper is to discuss the connections between drawing and the essential notions of *“visuality”* (Fiedler, 1887), *“Reflection-in-action”* (Schön, 1983), and *“Precedents”* (Hancock, 1986) for the benefit of learning, designing and researching.

VISUALITY AS AN ACTION, NOT A PERCEPTIVE TREAT

Konrad Fiedler took advantage of Immanuel Kant’s discovery about the active participation of intelligence in aesthetic matters. Far from the undeveloped status that previous theorists assigned to artistic issues, Kant defended that there is intelligence in art, the same kind of intelligence used for conceptual judging. But in art, intelligence determines the way the subject behaves when he/she judges a work of art, instead of determining the object itself. This is a pivotal moment in history because reason entered the realm of art without conditioning the works of art themselves. From then on, art has to be considered an equal among the supreme human expressions of science and ethics.

Having Kant deducted the participation of consciousness in the reception of art; Fiedler attempts to do the same with art production. What distinguishes Fiedler’s thinking from

his undisputable master Kant is its “*dynamism*” (Junot, 2004). For Fiedler, *visuality*, the main characteristic of art, is not the result of exaggerating the visual aspects of reality, to the detriment of other senses; or even a more sentimental approach that decreases the participation of the intelligence. *Visuality* is something that only appears through the manipulation of the material world done by the artist. From this point of view, *visuality* is something that the eye cannot do or find by itself, it is not something that is already in nature waiting to be discovered by privileged minds or eyes. *Visuality* is only reached through the motivated actions of the artist, and drawing is its main mean.

Fiedler situates the essence of art in the sense of vision. There is nothing like art in general, and fine arts like painting, sculpture and architecture share a common visual condition that benefits from the autonomy of vision. From this point of view, vision has a potentiality that other senses do not have. Touch, for example, cannot produce any enduring effect in our consciousness as there is nothing like “*verifiable tactile representation*” (Fiedler, 1887) that can be separated from the object. If the original object that produces the tactile sensation is not present, the whole perceptual experience of touching ends. Vision, on the contrary, is able to capture experiences in another way: a simple sketch is able to trap something of the visual essence of reality that would allow us to consider it from the visual point of view, even without having the object in front of our eyes. Moreover, a simple profile of an object would allow us to develop the configuration of the sketched object according to the specific “*sensitive certainty*” (Fiedler, 1887).

From this standpoint, it is possible to establish a conscious relationship with the world that surrounds us in two ways: scientifically by naming, formulating, signaling; and artistically by representing things as seen or even by representing them “*how they should be seen*” (Fiedler, 1887). The reasonable doubt that emerges in this point is how to assure the rigor or correctness of an image that has been developed in visual terms? If we aspire to equate art and science, there should be a certain type of rules that secures universality or at least provides sufficient objectivity to the whole process.

Kant’s theory establishes that there are no rules that determine what and how the work of art should be. Rules are not explicit in art and they are only present in the conduct of the subject. *Visuality* also has a special kind of normativity that is not explicit and is not separable from the artistic activity (drawing). The norms that can be found in the artistic activity are inside our consciousness and are those “*exigencies that consciousness poses to visuality*” (Fiedler, 1887). Those rules are only perceivable and materialized by the work of art itself, and they are certainly part of “*demonstrable physical events in the processes of perception and imagination, or that should at least be pre-supposed*” (Fiedler, 1887).

Kant founded the validity of aesthetic judgment in the normativity of the cognitive powers that could not be proved. He deducted that aesthetic judgment has to have a subjective common base that has to be “*the same in all men. This must be true, because otherwise men would not be able to communicate their representations or even their knowledge*” (Kant, 1790). Also for Fiedler there are not explicit rules in art production, only the regularity that is manifested in the normal processes of perception. The artist can develop this specific order by paying attention, not only to his/her eyes and imagination but involving his/her whole body and specially his/her hands in a process that starts always with a visual perception. From this point of view, the artist is not any more the romantic subject that has a special sensitivity, someone able to see what others cannot see or feel; but someone that is able to “*switch directly from perception to graphic expression*”, from perception to action (Fiedler, 1887).

VISUALITY TODAY

What makes opportune to rescue Fiedler's proposal today is his vindication of the idea of artistic activity as a unity mind-body. In current philosophical crisis, in which there are not new models of thinking and the old ones seem exhausted, it is opportune, once again, to vindicate a type of consciousness that does not involve the simple domination of the world. Equivalence between art and science should not mean a nostalgic yearning of the sort of rationality someone like Leonardo Da Vinci, for example, enjoyed centuries ago. In those times drawing was just a tool in the dogmatic attempt of the total rational explanation. Today, the situation is radically different: as Theodor Adorno said *"the whole is the false"* (Adorno, 1951). Nevertheless, precisely because cosmologies are ill-conceived, provisional and partial self-attentive notional scaffoldings are indispensable in our damaged era.

According to Fiedler, the meaning of artistic activity is based on its resistance to those *"powers of progress"* that *"only see in every action a means towards aims"* (1887). The interest behind the exhumation of Fiedler's proposal on the 21st century is propelled by the conviction that visual curiosity is still a lively impulse able to inspire, not only the production of art and architecture, but specially its learning. Autonomy of vision has not died in spite of the exponential expansion of audiovisual in the globalized society, the other way around. Thanks to the resisting autonomy of vision: *"now we see the artist beside the researcher"* (Fiedler, 1887).

VIRTUAL WORLDS AND REFLECTION-IN-ACTION

Donald Schön was invited by the Dean of the School of Architecture, William Porter, to investigate the unusual atmosphere at the design studios at MIT in the 1970s. The fact that no explicit content was delivered at studios, added to the curious commitment and devotion of architectural design students, was considered an interesting and relevant topic of study. Observing the practical work of architectural design studio Schön coins the notion of *"reflection-in-action"* (1983). Reflection-in-action should be understood as the ideal skill of all practitioners; it is an atypical knowledge (in action) that allows good professionals to improvise new solutions on the go. Reflection-in-action explains how good professionals are able to deal with unique, uncertain and contradictory problems.

Donald Schön discovers an astonishingly flexible mode of inquiry in the specific way students and instructors act at the architectural design studio. This particular mode of inquiry is able to do things that are almost impossible in the scientific mode of research. Studio research is able to re-frame ill-formulated problems; to attend details and the whole almost simultaneously; to move freely when is necessary but to assume constraints when the contrary is true; to dialog with the situation itself in the way John Dewey describes as *"transactional"* (Schön, 1987). The way architects work when they design is prescriptible for all other professions as architecture *"epitomizes the design professions, and designing, broadly conceived, is the process fundamental to the exercise of artistry in all professions"* (Schön, 1987).

After discovering architectural design's reflexivity, the ambitious plan of Schön is to extend its modes of inquiry to the whole educational system at research universities. In his opinion a different type of knowledge is required, an *"epistemology of practice"* (Schön, 1995). In that sense, and just as Fiedler does when he claims a special consciousness for artistic matters, Schön considers that the education of engineers, economists, etc. should have a way of experimentation that, respecting the scientific hypothesis probing, is adapted to the particular dynamic characteristics of professional problem solving. Thus, if scientific

research looks for truth, practical experiments, “*experiments on-the-spot*” (Schön, 1987), are meant to change the situation the professional works with. It is important to keep in mind that drawing is at the heart of the architectural experiments that inspires Schön’s general theory.

“*Virtual worlds*” (Schön, 1987) is what drawings are able to build in the architectural design process at the studio in Schön’s opinion. In the virtual worlds that architectural drawings facilitate “*the hypothesis must lend itself to embodiment in a move*” (Schön, 1987), which means that intellectual matters are translated into movements that are kept on the paper as drawing leaves traces of those movements. This sort of visual objectification permits to adapt the rhythm of the action during the experiments, makes reversible every one of the movements done, allows context to be adapted to satisfy the conditions of the experiment, and also permits to separate and combine elements at the will of the researcher-designer. Drawing is so attached to the idea of reflection-in-action that “*the sketchpad is the medium of reflection-in-action*” (Schön, 1987).

The problem of legitimacy is an important aspect of the particular experimentation that architects do. How to know when the ends have been accomplished? From the pragmatic point of view, the validity of architecture lies on the correspondence between drawings and building possibilities: “*the validity of the transfer depends on the fidelity with which the drawn world represents the built one*” (Schön, 1987). The representational potentiality of drawing in architecture is limited to building in Schön’s view, no further cultural expansions like in the so called “*paper architecture*” (Cook, 2008; Nesbitt, 1996) in his opinion.

Apart from pointing out the different types of tutoring, the main contribution of Schön’s analysis is the key role assigned to the practicum in education (Jaime and Lopez Reus, 2013). Tacit knowledge, “*reflexive thinking*” (Dewey, 1912), and the particular role of past experience, together with design experience itself is what encourages Schön to propose reflection-in-action as the model of a new epistemology of practice.

Past experiences in the context of reflection-in-action deserve a final consideration. Professional problems, different than scientific and technical ones, are characterized by uniqueness. Past experiences help practitioners to see the new situation as a previous one in a sort of provisional manner in which the particular characteristics of the new situation are too many and too much to be regarded. The following section discusses specific relationships between past experiences and drawing that are relevant for architectural experimentation and research-based education.

DRAWING FROM CURIOSITY

Curiosity is typically associated with processes of exploration and learning activated by the motivation of acquiring new skills or discovering new things (Edelman, 2014; Dewey, 1912). This exploratory attitude toward reality could be seen as a driving force behind the lack of understanding or state of unpredictability within creative activities. Curiosity is developed from situations associated with uncertainty or ambiguity such as design problems. Design deals with new and singular situations that cannot be addressed by applying pre-established rules. Designers do more than simply solve well-defined problems applying knowledge through technology. Rather than problem solving design process concentrates on reframing uncertain, contradictory and unique situations as a way to achieve original proposals.

In the midst of searching for innovative answers designers jump the gap of the unknown by seeing the current and unprecedented problems as familiar (Schön, 1983). Contrary to what it could appear at first glance, it is the necessity of originality what makes design to rely on precedents as source of inspiration. Schön asserts that in seeing unfamiliar situations as something already known or experienced, designers might pull out from his/her “repertoire” of examples, images, concepts, processes and attitudes (1983). However, the application of experienced rules to find the best means to reach an end is not enough because design practice does not fit the model of technical rationality. According to this, design practice consists in a “conversation with the materials of a situation” (Schön, 1983), in which the use of precedents or past examples must be connected with the current task. This means, that the adequacy or utility of new possibilities taken from the past must be discovered in action, which in turn means through drawing. The fact that drawing is involved in every design process opens the door to discuss the essential role of drawing within the study and use of precedents in design.

PRECEDENTS AS SOURCES OF INSPIRATION FOR DESIGN

Dewey, the true father of reflexive thinking theory, discovered that one goes back to past experiences and chooses from its complex and irreducible totality those aspects needed for making sense in front of new experiences (2005). Over time designers build their own repertoire of precedents and experiences that helps them to compare situations and learn by example. The consistency of design involves the visual consequences of “reflection-in-action” (Schön, 1983) and its capacity to improve the built environment. Designers can re-frame new situations by comparing the present design task with a known repertoire of precedents that collect similar problems or similar situations. The repertoire of preexistences becomes a continuous reference in which to trace back the questions raised during the design process. But the effectiveness of this strategy lies on the control that the designer must have over the possible choices. It involves a critical attitude toward traditional and historical knowledge.

The seminal theory of precedents of John Hancock resituates architectural work on the world of cultural forms making a basic distinction between historical knowledge and traditional knowledge (1986). Two different ways of knowing the past would define the concept of precedent: the universality and openness of history induce a superficial understanding of a great diversity of precedents, which translates into the availability of an unlimited number of architectural works of different historical periods for the designer. On the contrary, tradition involves depth of understanding and authenticity but lack of openness and no availability of choices. According to these facts, Hancock redefines precedents in a territory of exploration between history and tradition (1986). The questions to be posed are: How do designers build and cultivate their own repertoire of precedents? and how precedents are better discovered, studied and used in design?

The mentioned theory of precedents seeks to resolve this dilemma through two epistemological tools: First, the limitation of choices through selecting only portions of the past according to the present task; Second, the use of rigorous methods for analyzing the selected precedent. Thus, the criterion of functionality should be accompanied by a method of analysis that could effectively replace the lack of depth of historical knowledge and the lack of availability of tradition (Hancock, 1986). Drawing is the method, also in this case, to understand in depth a prior work of architecture and to become critical about cultural material within the design process.

DRAWING FROM THE PAST AND DRAWING FOR THE FUTURE

Drawing as the main tool for managing precedents, create visual totalities or virtual worlds able to imitate the comprehensiveness of history but preventing the limitations of the immersive knowledge of tradition. Cultural material coming from history and tradition can be critically transformed into sources of design ideas – spatial organizations, patterns, archetypal forms, ready-made principles- through drawing.

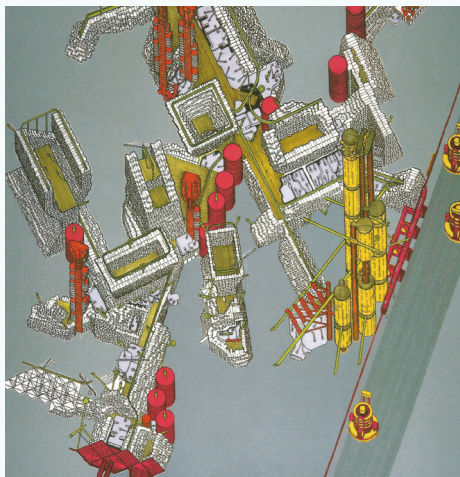
Designers use different types of representations in order to reflect upon prior work of architecture and to learn by example. In this context, orthographic drawings, archetypal diagrams and conceptual sketches become interpretations in which cultural and historical sources can be critically manipulated, arranged and included as material that inform design ideas.

In this view, drawing, rather than just an action or a tool for inquiry within the design process, is considered a rigorous method to analyze selections in an effective way (Hancock, 1986). Three modalities of drawing would define the original and fertile methodological research of precedents: Analytical (orthographic drawing addressing space, plan-organization, zones, façade compositions, spatial relationships, etc.). Experiential (sketches that involve itineraries, texture, ornament, character, etc.) and transformational, applying Derridian principles of deconstruction for manipulating form (Hancock, 1986).

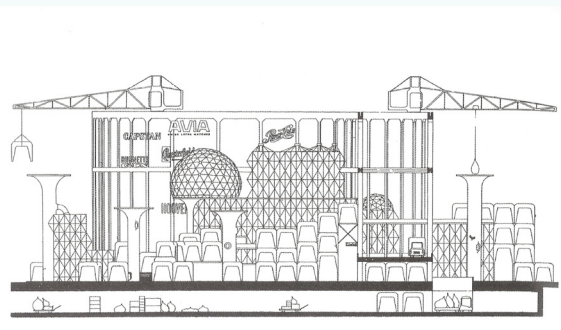
In the proposal *Precedents in Architecture* by Clark and Pause, diagrams keep a balanced dependency to the spatial and formal essence of architecture. The emphasis that abstraction produces in diagrams is used to connect the “commonalities of architectural ideas” (1996). In this case, no context, no socio-political, no technological issues are involved, just formative patterns, design parties and archetypes are considered important as they may lead to new design ideas. No periods, no styles, no names and dates is the conscious approach to the history of architecture. The use of diagrams, understood as visual abstractions that pretend to illustrate the “architecture of the idea itself” (Garcia, 2010), has become increasingly popular in architecture since the mid-1980s. The analysis of architects’ sketches offered by Kendra Shank (2005) offers the rigor of having the drawings and their ad-hoc linguistic critique together: this makes this approach a useful instrument in training to talk about what we see. In Groat and Wang’s *Architectural Research Methods* (2002), the authors declare faithfulness to Kantian art’s autonomy faithfulness in which is, maybe, the most important effort done for connecting architectural design and academic research.

When drawing does not pursue *visuality* but it turns a communication media, *virtualism* is round the corner. “*Virtual Architecture*” (Jaime, 2002) is more related to politics than to architecture. Even considering drawing as the motive force of architecture, the virtual architectural experiments show that their focus is not space but iconography.

Defined as attacks of drawers against spoken or written statements (Cook, 2008), the socio-cultural motivation of virtual architecture generates another sense of the virtual worlds totally different from those Schön talks about. In politically motivated architecture, representation has more temporal than spatial connotations. In these cases, verisimilitude becomes more important because images have different motivations than the particular “representation as seen” (Fiedler, 1887). This type of drawn architecture aspires to illustrate utopias which, in contemporary world, have become neoliberal projects that use its revolutionary powers for keeping things as they are (Gray, 2008).



▲ Figure 1 Peter Cook, Plug-in City, 1964. Collage with printed papers and ink, 69,5 x 75,9 cm. Collection of Modern Art, New York.



▲ Figure 2 Peter Cook and David Greene, Nottingham Shopping Viaduct, 1962. Ink line drawing, 25 x 15 cm.

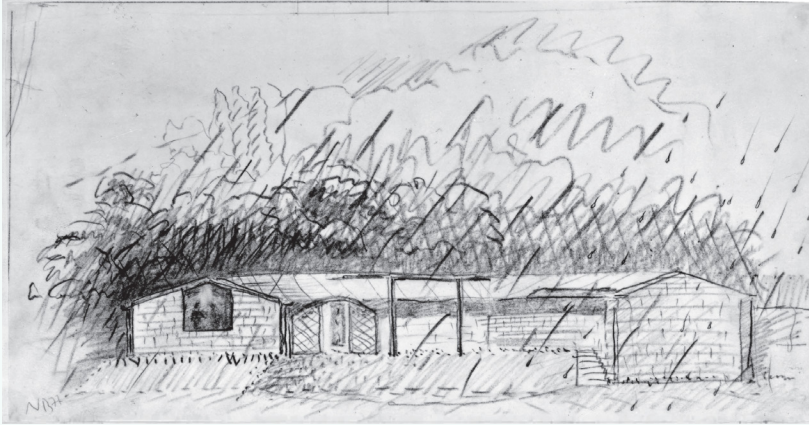
FROM PURE VISUALITY TO VIRTUALISM

Connecting *reflexiveness* and drawing is the itinerary with which this paper has gone from pure *visuality* to *virtualism*. The objective of the study is to show the particular participation of drawing in the seminal introduction of *reflexiveness* in visual arts (Fiedler, 1887); in the implementation of *reflexiveness* in the architectural design studio (Schön, 1987), and its use in the adaptation of historiography to the creative process (Hancock, 1986). In all these three cases, the aim has been to show the proved possibility of connecting art, practice and history with our current world.

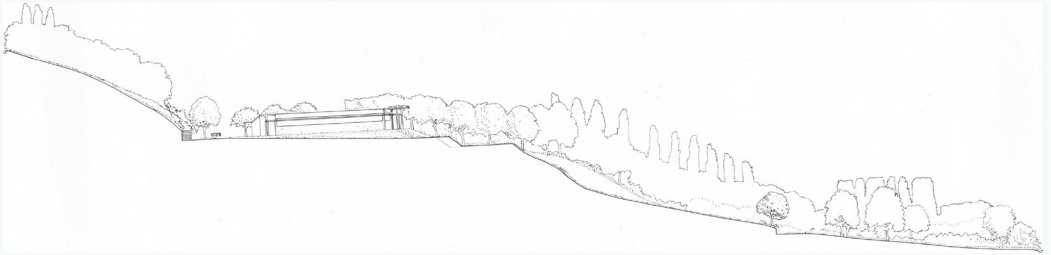
Drawing has a proved capacity of unifying ingredients of diverse natures in a convincing manner in each of the three realms analyzed. In some cases, the simple presence of drawing appears to prevent dogmatism from taking command, and, in other cases, it looks exactly the opposite. *Reflexiveness*, the notion that has been always omnipresent through this paper, still remains at this point as a tricky subject, as things and their representations tend to mingle capriciously when the aims of aesthetic inquiry are not fully aesthetic. Surely implicit art rules prevent rational dogmatism, but it is also true that the typical opacity created by rules implicitness has been frequently filled with simple propaganda in most of the so-called engaged art.

In the case of the notion of reflection-in-action, which certainly cannot be considered the essence of a “*coherent epistemology of professional practice*” (Webster, 2008), at least it recognizes the epistemological status of vision in the design inquiry: Schön’s proposal is still the most stimulant analysis of the reflexive nature of architectural design studio, and it definitely recuperates Dewey’s claims for a reflexive education in the realm of current research universities. The perennial discomfort of architecture inside research universities has been alleviated greatly by the brave vindication Donald Schön did of architecture’s particular epistemological assumptions, among which drawing preserved an essential role.

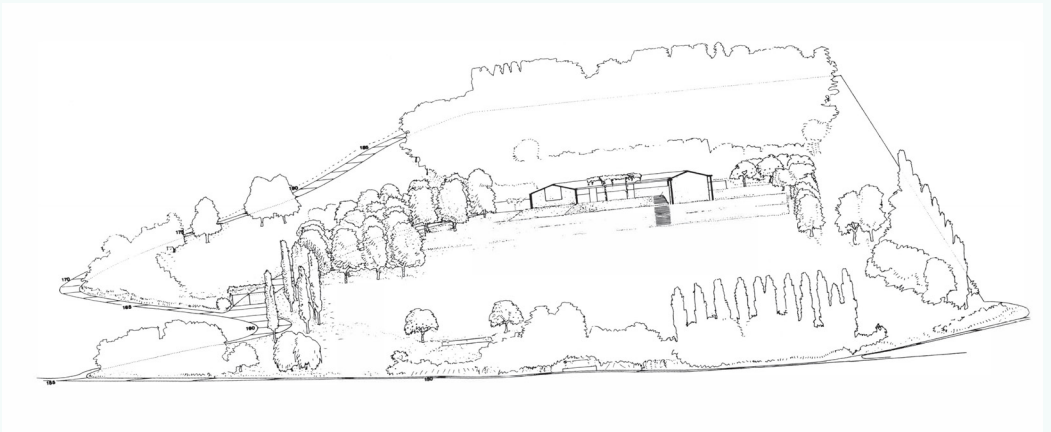
It seems evident that dogmatism enters in play whenever the pair *reflexiveness-visuality* is broken. George Soros has named “*reflexivity*” (Soros, 1987) the main problem of



▲ Figure 3 Juan Navarro Baldeweg. Sketch of the House of the Rain on a white background, 1979. Pencil drawing, 30x40 cm.

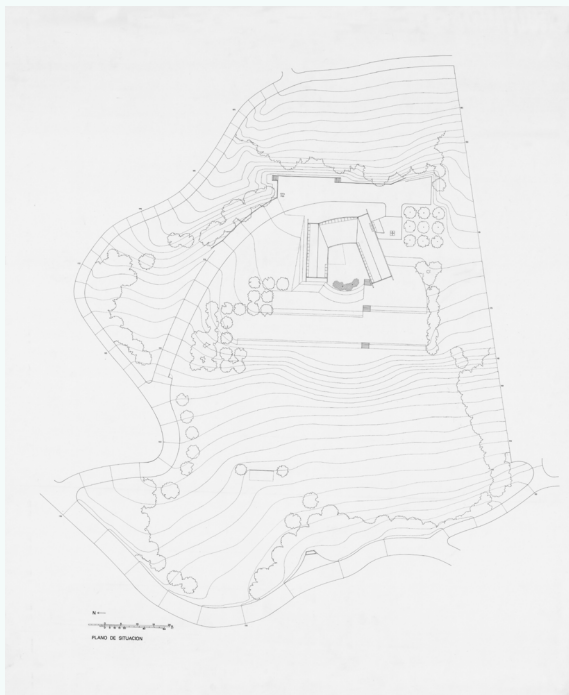


▲ Figure 4 Juan Navarro Baldeweg. House in Lierganes, Santander, 1979. North elevation. Ink on paper, 40 x 60 cm.



▲ Figure 5 Juan Navarro Baldeweg. House in Lierganes, Santander, 1979. West elevation. Ink on paper, 40 x 60 cm.

contemporary economy, as people tend to confuse their interpretations with reality itself. Other experts [Carrier and Miller, 1998; Davis and Klanes, 2003; Bordieu, 1992] consider that the growing abstraction that is affecting economy - which some called “virtualism” [Carrier and Miller, 1998] as it separates economy from society - started with business schools and consultancies and the way they spread the “cases of study” [Carrier and Miller, 1998] as an infallible methodology of intervening in real problems. Donald Shön



▲ Figure 6 Juan Navarro Baldeweg. House in Lierganes, Santander, 1979. Site plan. Ink on paper.

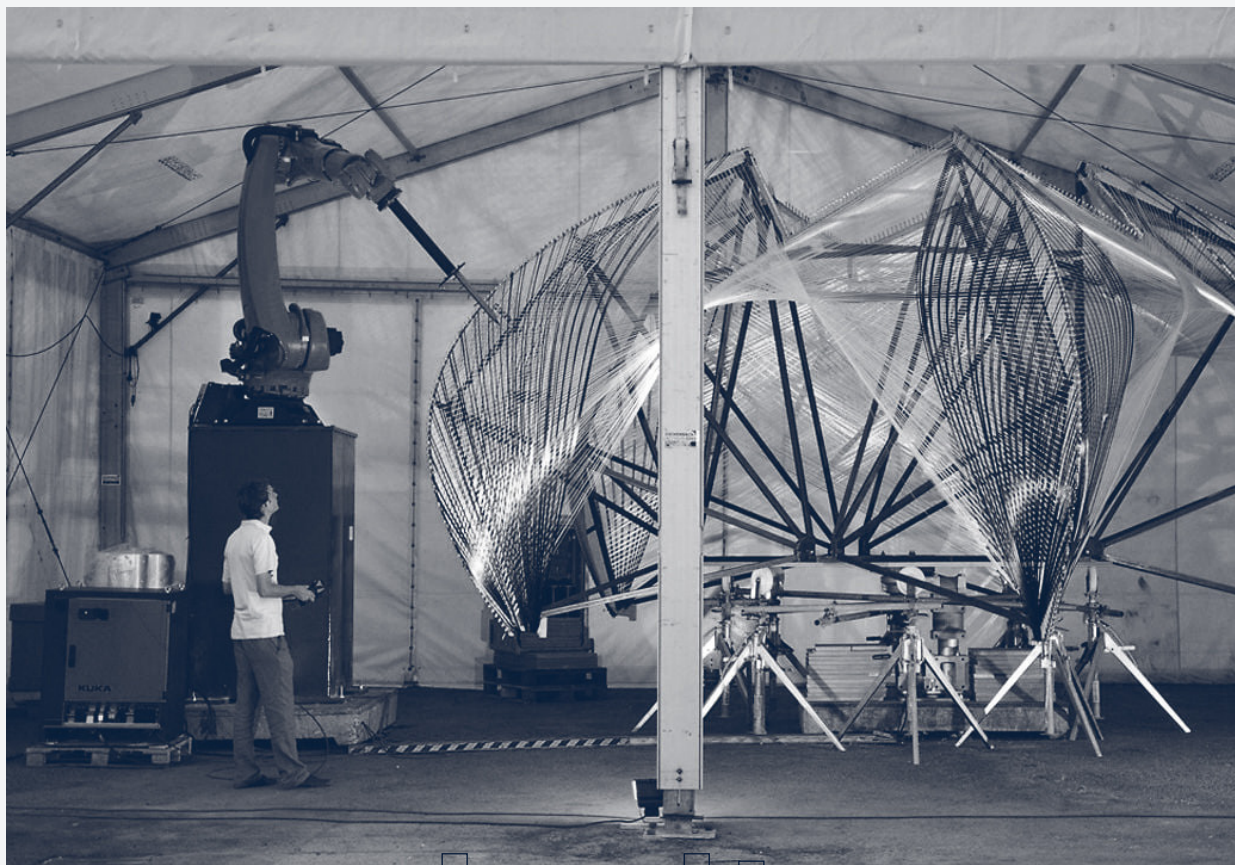
himself came to MIT to study the architectural design practice after being a consultant and his reflective proposal went back immediately to business school education.

We do not have a clear explanation of why drawing seems to prevent certain types of dogmatisms, as it is evident in the work of Juan Navarro Baldeweg (Navarro, 2007) and some other artist-architects like Alvaro Siza and Steven Holl. It might be that drawing's specific completeness, equidistant from perception and intellectualization, works as a break against abstractionist and dualist temptations. The fact that even those products of architectural *virtualism* that hang on the walls of some of the most important art museums do so thanks to its expressive quality, revives the faith that drawing can tilt the curse or cure dilemma of *reflexiveness* clearly in favor of art and artistic attitudes.

REFERENCES

- Adorno, T., [2005]. *Minima Moralia: Reflections from Damaged Life*. London: Verso
- Archer, B., [1995]. The Nature of Research. *Co-design Interdisciplinary Journal of Design*, January issue, pp. 6-13.
- Biggs, M., [2004]. Learning from experience: approaches to the experiential component of practice-based research. In: *Forskning, Reflektion, Utveckling*. Stockholm: Vetenskapsrådet, pp. 6-21.
- Boyer, E., [1996]. The Scholarship of Engagement. *Journal of Public Service & Outreach*, 1(1), Spring issue, pp. 11-20
- Bourdieu, P and Wacquant, L., [1992]. *An Invitation to Reflexive Sociology*. Chicago: The University of Chicago press.
- Carrier, J. and Miller, D. eds., [1998]. *Virtualism: A New Political Economy*. Oxford, New York: Berg.
- Clark, R. and Pause, M., [1996]. *Precedents in Architecture*. New York: John Wiley & Sons
- Cook, P., [2008]. *Drawing, the motive force of architecture*. West Sussex: John Wiley & Sons
- Davis, J. and Klaes, M. 2003. Reflexivity: curse or cure? *Journal of Economic Methodology*, 10(3), pp. 329-352
- Dewey, J., 1912. *How we think*. Boston, New York, Chicago: Heath & Co
- Dewey, J., 2005. *Art as Experience*. New York: PenguinGroup.
- Edelman, S. [1997]. *Curiosity and exploration*. Northridge: California State University
- Fiedler, K., 1887. Sobre el Origen de la Actividad Artística. In: Pérez Carreño, F., ed. Translated by Romano, V. 1990. *Escritos sobre arte*. Madrid: Visor, pp. 169-290.
- Frayling, C., 1993. *Research in Art and Design*. Royal College of Art Research Papers, 1(1).
- Gay, D., 2007. Modernism, Reflexivity and the Washington Consensus. *Journal of Economic Methodology*, 14(1), pp. 83-105.

- García, M., 2010. *The Diagrams of Architecture*. West Sussex: John Wiley & Sons
- Gray, J., 2008. *Black Mass: Apocalyptic Religion and the Death of Utopia*. New York: Farrar, Straus & Giroux.
- Groat, L. and Wang, D., 2002. *Architectural Research Methods*. New York: John Wiley & Sons.
- Hancock, J., 1986. *Between History and Tradition: Notes toward a Theory of Precedent*. The Harvard Architecture Review. Precedent and Invention, 5, pp. 65-77.
- Jaime, M., 2000. *La Dimensión Reflexiva de la Arquitectura Moderna*. Pamplona: Eunsa
- Jaime, M. 2002. Arquitecturas virtuales. *Revista de Occidente*, 253, pp. 125-135.
- Jaime, M. 2009. John Gray, o el pragmatismo inteligente. *Revista de Occidente*, 340, pp. 125-146
- Jaime, M. and Lopez Reus, E., 2013. Learning in Music and Design as an Example of Reflective and Collaborative Education. In: GSE 2013. The Global Summit on Education. Kuala Lumpur 11-12 March 2013. Kuala Lumpur: GSE 2013, pp. 578-586.
- Jaime, M. and Lopez Reus, E., 2014. Building by Doing: The Reflexive Nature of Modern Architectural Education and Research. In: DOCOMOMO 2014. 13th International Conference: Expansion and Conflict. Seoul, Korea, 24-27 September 2014. Seoul: DOCOMOMO Korea.
- Junod, P., 2004. *Transparence et opacité. Essai sur les fondements théoriques de l'art modern*. Nîmes: Éditions Jacqueline Chambon.
- Kant, I, 1790. *Kritik of Judgment*. Translated by Bernard, J. H., 1892. New York: Macmillan & Co.
- Kant, I. 1781. *Critique of Pure Reason*. Translated by Muller, F. M., 1922. London: Macmillan.
- Navarro Baldeweg, J. 2007. *Una caja de resonancia*. Valencia: Pre-Textos.
- Nesbitt, N., 1996. *Theorizing a New Agenda for Architecture: An Anthology of Architectural Theory 1965-1995*. New York: Princeton Architectural Press.
- Ortega y Gasset, J., 2002. *What is knowledge?*. Translated and edited by Garcia-Gomez, J. Albany: State University of New York Press.
- Schank, K., 2005. *Architects' Drawings. A Selection of Sketches by World Famous Architects through History*. Amsterdam: Elsevier Architectural Press
- Schön, D., 1983. *The Reflective Practitioner. How professionals think in action*. New York: Basic Books.
- Schön, D., 1987. *Educating the Reflective Practitioner. Toward a New Design for Teaching and Learning in the Professions*. San Francisco: John Wiley & Sons
- Schön, D., 1995. Knowing-in-Action. *The New Scholarship Requires a New Epistemology*. *Change*, 27(6), pp. 27-34.
- Scrivener, S., 2009. The Roles of Art and Design Process and Object in Research. In Nimkulrat, N. and O'Riley, T., ed. 2009. *Reflections and Connections on the relationship between creative production and academic research*. Helsinki: University of Art and design Helsinki A 93, pp. 69-80.
- Soros, G. 1987. *The Alchemy of Finance. Reading the Mind of the Market*. New York: Wiley
- Till, J., 2005. What is architectural research? *Architectural research: three myths and one model*. London: RIBA Discussion Paper.
- Webster, H., 2008. Architectural Education after Schön: Cracks, Blurs, Boundaries and Beyond. *Journal for Education in the Built Environment*, 3(2), pp. 63-74.



curiosity
producti
risk
participation



Keynote

Achim Menges

Production

Technological progress has always been a catalyst for change in architecture. Today, technical advancements across multiple disciplines suggest a profound transformation in the production of architecture, both intellectually in the process of design and physically in the process of construction. In the context of an increasingly ubiquitous digitalisation, the related questioning of established modes of design thinking, the deterioration of conventional disciplinary hierarchies and the rapid erosion of industrial logics of production is beginning to forge new alliances between the fields of design, engineering, natural sciences and humanities. Together with the continuing progress in computational design, simulation and fabrication this opens up the possibility to fundamentally rethink the way the future built environment is conceived and materialized.

‘The deterioration of conventional disciplinary hierarchies and the rapid erosion of industrial logics of production is beginning to forge new alliances between the fields of design, engineering, natural sciences and humanities’

on

The current transformation in the production of architecture needs to be reflected in the way the next generation of architects is taught and possible futures of the discipline are researched. Educational models and pedagogies need to align disciplinary concerns with the exploration of the advancement of technological processes as novel tectonic, structural, spatial and ecological potentials, and their significant cultural and social ramifications. This calls for educational programme that are ever more inquiry-oriented, experiment-based and shaped around multidisciplinary approaches to design. Teaching and research need to encourage a conjoining conception of technological innovation and cultural production, emphasising rigorous investigation and critical reflection on the implications and potentials of technological innovation for contemporary and future design research and architectural practice. Most importantly, the enquiry of such topics need to be exposed not only as a technical challenge, but primarily as an intellectual venture, in order to reveal and explore their significant cultural impact.

The robot and the swallow: Sustainable practice in a digital world

Guan Lee & Eleanor Morgan

The Bartlett School of Architecture, UCL, UK

With the advent of digital revolution, we are inventing new production methods, but the question remains: how can we make products with new tools without compromising achievements from the past? What are the key benefits of engaging with digital tools when working with a material steeped in history? In rethinking modes of production, the more pressing question now is how can issues of sustainability play a role?

We aim to spark a debate about sustainability in material practice, using an industrial robotic arm to build with local clay. Our project aims to look at ways in which digital and traditional clay processes could be combined. Already, a division is implied. Yet over the course of the project, what has been revealed is a far more complex interplay between what we might define as digital and manual processes, or simple and smart materials. As two practice-based researchers from the field of architecture and art, we have approached the question of sustainability from overlapping spaces: inside and outside the workshop.

INSIDE THE WORKSHOP

Our project is based at Grymsdyke Farm, a research facility, fabrication workshop and living-working space for architects, artists, designers and those interested in materials and processes of making. Set in the village of Lacey Green in Buckinghamshire, the aim of our production is exploring the essential connections between processes of design, making and place. Over the last few decades, many brick-making factories in Buckinghamshire have gone out of business bar one, H.G. Matthews. The farm itself sits on a layer of clay geologically known as “clay with flint”. Due to the large number of flints, the processes of separating out the clay deem this particular resource uneconomical. Instead, we decided to use one of H.G. Matthews’ brick-making clays, Chalfont clay. The key advantage of this clay is that it is suitable for brick-making straight out of the ground. This particular aspect suited our initial production goal: local clay with minimal preparation before loading the material into the clay extruder. Chalfont bricks are low firing bricks, typically not fired higher than 1000 degrees Celsius. This means bricks not particularly hardwearing or high in strength. With these initial constraints, the project set out to design and fabricate a site-specific fired clay-building module.

Clay in Buckinghamshire is historically used for brick making. We are mindful that clay comes from natural deposits underground and is finite in quantity. Once depleted, it is not reversible and we have content with open



▲ Figure 1 Robotic arm extruding multiple segments of clay objects. Photo credit: Guan Lee.

scars left in the landscape. High-embodied energy is another issue with fired-clay as a material. Brick making is now a disappearing industry in Buckinghamshire. Rising cost in production drove this industry to the ground. How can we maintain our engagement with clay as a material? Can new technologies provide the answers, or maybe we should cast a wider net? One can argue that manual processes of working with clay can change, and tacit knowledge that developed over time will evolve. Or, perhaps this discourse must go beyond utility and efficiency. Somewhere between a brick and a decorative terracotta block, earth works by human or animals, there is room for rethinking design and making of architectural ceramic.

Our robotic fabrication setup is modeled after a standard 3D printer: a reservoir of material dispensed at a specific rate continuously, or with a stop-start option, simultaneously being directed following a pre-determined path. In order to dispense the clay, we chose to work with an existing pump manufacture by ViscoTec in Germany (Figure 1). Their pump works with a rotating displacement principal. It is “comparable to an endless piston, which conveys the product from the suction end to the discharge end, thus building up a pressure difference.” This pump is then connected to our 6-axis standard robotic arm. Specifically in the production of clay objects, this process is identical to the traditional ceramic hand-building process with clay, also known as coiling. In digital fabrication, the paths that the material dispenser is following are often generated or derived from a 3D digital model. The thinner the dispensed material, the closer the 3D printed object is to the initial digital model. There are a few potential advantages that stand out immediately using a digitally-controlled tool. First, repeatability: a clay object can be copied repeatedly like a casting



▲ Figure 2 Jessie Lee touching up the clay column that has been assembled together. Photo credit: Guan Lee.

process but without the effort of building moulds. Second, variety: it is as easy to repeat the fabrication of the same geometry, as it is to build something unique each time. Third, accuracy: multiple elements can be assembled together to form an overall geometry with more precision. These are potential advantages, because the final product must be able to perform at least as well as its non-digital predecessors. Further, there are few well-known limitations in 3D printing. First, scaffolding: all 3D printed objects must self-support as the material builds, layer upon layer. Unsupported length and cantilever are problematic. Second, size: the reach of the printer itself limits the scale of buildable object. Third, layering: these 3D printed objects are not monolithic, but fused together with potential failure like delamination. The system we put together at Grymsdyke Farm aims to seek out these issues by going back and forth between traditional ceramic technology and experimental methodologies.

The first task in preparing the Chalfont clay is to determine an optimum clay viscosity for our pump. This has immediate impact on the speed of extrusion versus the rate of clay dispensing. The consistency of clay ideal for our pump in traditional ceramic terms is somewhere between throwing clay and slip. We consulted a number of ceramicists including Jessie Lee who has been working with clay for over 30 years. The general consensus is that the moisture content of clay is often understood through **feel** or **touch**. The advice we got from H. G Matthews is to test the material again and again from the process of building, to drying and firing. Initial tests with a series of small and single walled clay columns built with 5mm clay beads would become unstable and begin to collapse beyond the built

height of 100mm. Also, if the clay column itself is slanted, it cannot be extruded beyond 30-degree angle. Depending on the geometry, we struggled to build beyond the height of 150mm as one continuous build. In order to overcome these limitations, we built multiple clay objects at the same time and, after each 150mm build, we would let the clay dry for up to 5 hours depending on the temperature and humidity level of the day, before building the next section. Ceramic objects can be fabricated in parts, a teapot for example: the pot, the spout and the handle are often made separately and joined together with clay slip (Figure 2).

It is almost cliché in the industry to suggest that a sustainable practice is one which is adaptable, evolving and engaging with both traditional practice and advanced technology. Our observation so far with experiments of 3D printing clay objects is that the balance between traditional and digital processes is not easy to strike. The weight of established ways of working with clay and the material's behaviors can be overwhelming. In traditional hand coiling, the beads of clay are pushed together and 'flattened' with a wooden paddle. This will ensure that the layers of clay properly adhere together. With the digitally coiled clay, it is not possible to smooth the layers over, because the hand cannot decipher the original geometry contoured digitally: moreover we find ourselves making geometry with areas not reachable by hand. In some cases, our clay object delaminates, or a visible gap develops during the drying or bisque-firing process. But, if this can be overcome, the digitally-striated pattern is a unique feature that has clear ornamental quality. One technique we employed to ensure better cohesion between layers is to set the height layer of extrusion smaller than the size of the extruded bead. But, with time, as the printing process progresses, the clay dries and shrinks and the gaps widen. This problem is exacerbated if the printing process is not continuous. The pre-determined path of the clay extruder cannot reconcile with the dynamic and plastic material.

What is sustained in using locally available material to construct our environment is not only economical and practical, but also of cultural and environmental significance. In Raymond Williams' 1976 seminal book *Keywords*, he put 'culture' into wider context, beyond references to mere physicality of our activities, in this case, making with clay. We have also to recognise the "*intellectual, spiritual, and aesthetic*" developments as a way of living. The tangible artistry of making in a community by this definition is cultural. Like clay from underground, culture can be malleable, a perfect blend of "*resistance and yielding*". Each and every one of us is like a fired brick, shaped to be the same but universally unique. As communities, we make architecture with bricks, bound together, layers upon layers, above ground as lore of our cultures, mirroring the vicissitude of life.

BEYOND THE WORKSHOP

Image one: a young man beds down for the night on a cement floor beside his robot. The robot extrudes rings of clay, one on top of the other. After it has produced seven layers, it has been programmed to pause to allow the clay to dry so that the structure does not collapse. The man sets an alarm every few hours. He gets up and restarts the robot. Each time it curls out another seven layers of clay on top of the dried layers. The clay dries. The alarm sounds. The man gets up and restarts the robot. Sometimes the small curls of clay extruded by the robot do not create a neat circle; the end of the ring hangs down a little. In this case, the man reaches in with his finger and carefully nudges the clay back into place.

Image two: a builder is repairing a cob wall. It is made from a mixture of clay, straw, dung, gravel, sand and water, and trodden together by humans. Every morning she arrives at the site to find that a swallow has started building its nest towards the top of the wall. There is



▲ Figure 3 Barn Swallow building its nest. Photo credit: John Rakestraw.

a curve of mud pellets stuck to the wall, eighteen centimeters wide and mixed with bits of grasses and horsehair. Each morning, she has to remove this nest before beginning work on the cob wall. She uses the same material as the swallow's nest, but in a form more suited to humans. As the cob wall dries it will continue to breathe, responding to the surrounding changes in temperature and humidity. "Cob," she says, "is a *smart material*."

These images could represent two distinct processes that we might call *new* and *old* or *digital* and *traditional*. On one side, the robot, digitally programmed to repeat a movement in space. It never becomes exhausted by its labour, but it relies on the exhaustible energy resources that power it. On the other side, is the cob. Made most often from the land on which it is built, cob structures are unbaked earth. It requires the labour of humans, or other animals, to combine the mix. Like other earth building processes, a successful build relies on dry, warmish weather and is therefore a seasonal practice that has been carried out by humans for thousands of years. But as the two images suggest, these processes are not cleanly divided. The builder described the ancient clay cob mix as a "*smart material*", a definition more usually applied to recently designed new materials, while the high-tech clay dispensing robot had to be carefully observed and assisted by human hand. One of the similarities of these two methods is their laboriousness. The robot cannot manage alone. Instead, it must be watched, restarted, and corrected if necessary. It is unforgiving, inflexible. The cob must be carefully mixed and applied, and because it retains its organic behaviour it too must be watched and attended to throughout its lifetime. These are high-maintenance processes, with very limited production – neither has been able to produce structures with the speed or scale of brick building.

As an artist, my role in this project has been to invite the contribution of different clay makers and experts and to investigate the geological and cultural significance of this material. In spite of our interest in the composition of clay as a natural material, we began with a focus entirely on human practices carried out predominately within the workshop and studio. However, as the project has developed, my interest has expanded beyond the workshop to consider other making processes that surround and inhabit this site: the making processes of other animals. I would argue that by expanding our understanding

of clay practices beyond the human we both broaden the imaginative potential of the project, and crucially begin to consider human making as only part of a broad ecology of organisms forming and reforming their environment.

To return to my two images of the robot and the cob builder, there is a third maker in the story that may offer another angle of investigation: the swallow building its nest (Figure 3). The workshop at Grymsdyke Farm is surrounded by the remains of swallows' nests under the eaves, where they return to every summer from their winter home in South Africa.

To construct their nests, male and female swallows will collect mud in small pellets from the surrounding area, which they mix with grasses and horsehair. The mix is very specific to each swallow species. For example, even if they are nesting in the same environment, a cliff swallow will mix together a sandy consistency, while the barn swallow prefers a more silt heavy mixture.

The nests are built of around 1500 mud pellets – tiny balls of wet soil. This is a vague term, because its composition differs depending on the geological history of an area. It is also given different names depending on the size of the soil particle. Clay is simply any particle of soil smaller than 0.002mm in diameter. If the particles are larger than this, it is defined as silt, then sand, then gravel and so on up to larger boulders. How these different sized particles are combined dictates the properties of the mixture. Clay plays a specific role in that it forms a bridge between larger particles of sand and silt, and therefore provides the basis of the adhesive quality we associate with mud on a larger scale.

Swallows begin building their nest by applying a three-inch curved shelf of mud pellets on to a sheltered wall. For the purposes of nest building, the suction-like action of the clay in the mud will stick together the different particles, but as the birds are building on a vertical wall they need a very strong adhesive for their nest. This is provided by their saliva, which mixed in with the mud creates a sticky bond with the wall, and between the mud pellets.

The swallows now face the same two problems as the human clay makers inside the workshop. The first is: How to make clay structures that don't collapse under their own weight. All three makers have arrived at the same answer to this – they take breaks, pausing after a few layers to allow the clay to dry and the water to evaporate. In a swallow's nest the different layers are clearly visible – a physical record of the moments when the swallow took a break in building. So, it seems that for all the makers, 'stopping' making at regular intervals is vital to the process of making.

The second problem is how to make a strong clay structure without cracks developing. These appear when there is different moisture content in the clays being joined, or when there are air pockets. The answer is agitation, which will moisten the clay and help it to bind. A cob builder does this by treading on the clay mix. The swallow achieves this by vibrating its head quickly as it applies each pellet. This action both softens the pellets that have already been joined to the nest, and creates a watery clay slip that flows into any crevices and fills the air pockets to create a strong structure.

Although we had explored combining clay with grasses to create cob, we hadn't tried combining it with saliva to create a strong bond, so I decided to try imitating the making processes of the swallow (Figure 4).

Faced with a ball of clay, I bit off a pellet, chewed it and rolled it around with my tongue.



▲ Figure 4 Mimicking the swallow. Photo credit: Eleanor Morgan.

Human mouths, I found, are not designed for building. Firstly, we have more fully developed taste buds than a bird. My body's response to clay was that it was not edible and it should be rejected. This is a very strong urge to try and resist, and it made me shut my eyes – perhaps because in addition to the disgusting taste I was also biting off something that resembled excrement. When it came to sticking together the pellets to form a structure, my lips were floppy tools compared with a swallow's probing beak, but my tongue was an excellent thing – able to press and mould the pellets into shape. But I couldn't vibrate my head as quickly as the swallow. The addition of saliva to the clay, however, did create a good adhesive but at the expense of my own disgust.

The repetitive movements of the clay-dispensing robot are perhaps better suited to imitate the regular vibrating movements of a swallow's beak, and this action might allow us to create stronger structures. What the robot can't do, however, is use the local materials as the swallow and cob builder can. Nor can either the robot or the cob builder use the sticky adhesive of saliva. Each of these animals, materials and processes has specific capacities and limitations. However, by expanding our attention to processes beyond the human, we find building practices that might productively inform our own methods, and vitally we broaden our understanding of what it means to make in the wider ecology.

CONCLUSION

Our investigation into the sustainable potential of combining digital and traditional clay making processes has revolved around the figure of the robot: an piece of factory machinery rescued and given new life in the environment of the workshop. No longer one of many, this robot is now part of a cottage industry and as such its capacities are available to be experimented with in new ways – perhaps even used ‘wrongly’. Our understanding of sustainable practice is that it is one that is both culturally and ecologically sustainable – it makes with its environment whether inside or outside the workshop. A cottage industry-like practice allows us to look outside the modes of mass production. The robot is no longer fixed in its purpose to create cars, rather it is a tool that moves in space which can be used experimentally. Outside of industrial scale production, diverse materials, processes and tools can be combined: the arm of the robot, the feet of the cob-builder and the beak of the swallow.

REFERENCES

- Geoff Larminie, ‘The Geology of the Chilterns’, Chloesbury and St Leonard’s Local History Group website, retrieved 20 December 2015, <http://cholesbury.com/documents/hccpsgeology2003.pdf>.
- Visco-Tec, The Endless Piston Principle, website, retrieved 5 January 2016, <http://www.viscotec.de/en/technology>
- Raymond Williams, *Keywords: A vocabulary of culture and society* (London: Fourth Estate, 2014), 88.
- Gaston Bachelard, Translation by Kenneth Haltman, *Earth and Riveries of Will: An essay on the imagination of matter* (Dallas: The Dallas Institute Publications, 2002), 57.
- Rebecca Reid, in discussion with the author. February 14, 2015. Clay Workshop at Grymsdyke Farm, Buckinghamshire.
- “The Cob Buildings of Devon: History, Building Methods and Conservation.” Devon Historic Buildings Trust (January, 1992)
- Osman Attman, *Green Architecture: Advanced Technologies and Materials* (New York: McGraw-Hill, 2010), 125.
- E. Morgan “Sticky Layers and Shimmering Weaves: a comparison of two human uses of spider silk.” *Journal of Design History* (Vol. 28:3, 2015)
- Mike Hansell, *Built by Animals: The Natural History of Animal Architecture* (Oxford: Oxford University Press, 2009), 75.
- Paul Jaquin and Charles Augarde. *Earth Building: History, Science and Conservation* (Bracknell : IHS BRE Press, 2012), 33.
- Peter Goodfellow, *Avian Architecture: How Birds Design, Engineer and Build* (Lewes: Ivy Press, 2013), 84.

RAF | A framework for symbiotic agencies in robotic – aided fabrication

Alicia Nahmad Vazquez & Dr. Wassim Jabi,

Welsh School of Architecture, Cardiff University, UK

ABSTRACT

The research presented in this paper utilizes industrial robotic arms and new material technologies to model and explore a different conceptual framework for ‘robotic-aided fabrication’ based on material formation processes, collaboration, and feedback loops. Robotic-aided fabrication as a performative design process needs to develop and demonstrate itself through projects that operate at a discrete level, emphasizing the role of the different agents and prioritizing their relationships over their autonomy. It encourages a process where the robot, human and material are not simply operational entities but a related whole. In the pre-actual state of this agenda, the definition and understanding of agencies and the inventory of their relations is more relevant than their implementation. Three test scenarios are described using human designers, phase-changing materials, and a six-axis industrial robotic arm with an external sensor. The common thread running through the three scenarios is the facilitation of interaction within a digital fabrication process. The process starts with a description of the different agencies and their potentiality before any relation is formed. Once the contributions of each agent are understood they start to form relations with different degrees of autonomy. A feedback loop is introduced to create negotiation opportunities that can result in a rich and complex design process. The paper concludes with speculation on the advantages and possible limitations of semi-organic design methods through the emergence of patterns of interaction between the material, machine and designer resulting in new vistas towards how design is conceived, developed, and realised.

1. BACKGROUND

In this pivotal time when much rewriting of contemporary history is happening regarding how architecture is conceived and how it is produced (Speaks 2011),

This paper focuses on developing a framework for symbiotic agencies in robotic-aided fabrication through an analysis of the different agencies, their influence on the design process and the examination of several case studies. New digital tools, and more specifically robots, are often thought of as an extension of the designer’s hand. Through iterative feedback mechanisms and observation of the relations created between the designer and the robot, this paper speculates how a deeper collaboration that acknowledges the “*potential otherness*” (Picon 2004) of these tools, through a learning-by-design method, could lead to the creation of new choreographies for architectural design and fabrication.

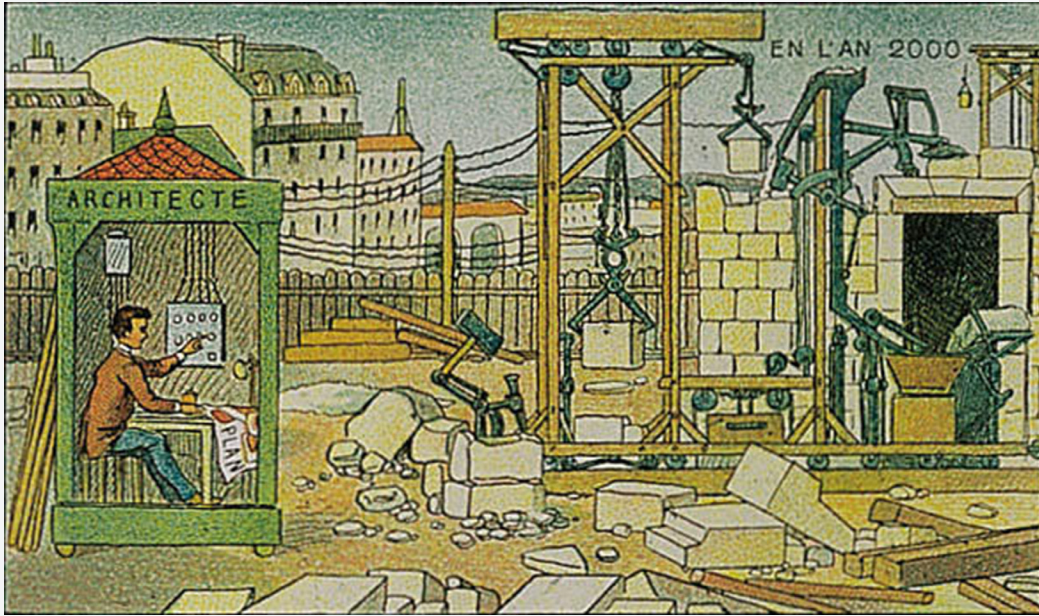
Although industrial robotic arms have existed since at least the mid-1960s within specialist environments, it is only in the last two decades that they have started to colonise other locations. Robots and, more specifically, robotic arms, are not a black box that will change construction in the future. From the moment Gramazio and Kohler started their laboratory at the ETH in Zurich in 1995, robots in architecture have been concrete things with character, limits, and influences. If architects are going to work with robots, it is important to define the means and frameworks for collaboration, to design potential interactions and choreographies with them. Robots invite us to rethink the traditional unidirectional workflow from 'digital design' to 'physical production' that currently exists in construction and digital fabrication processes, to use them as more than just another fabrication tool.

The cultural impact of techniques is undeniable. Lewis Mumford, in his book *Techniques and Civilisation*, clearly correlates the changes in the physical environment at the beginning of the 20th century, after the Industrial Revolution, with the changes in the mind. He rejects the idea that techniques can develop in isolation, uninfluenced by any other human desires than those from the people directly connected with their invention (Mumford 1959). The current scenario is of relatively unchanged humans interacting with robots and design technologies. Maurice Merleau-Ponty suggests that people can only incorporate instruments into their physical sensibilities through the experience of manipulating them (Merleau-Ponty 2013), as robots become more ubiquitous in architecture this scenario is likely to change. A future is foreseen where multiple agencies from human and non-human origin interact collaboratively to create better designs.

This paper starts by describing each of the agencies: robot, human, material, and their importance in the architectural process. Then it proceeds to analyse, through case studies, different interactions with varying degrees of participation from the different agents during the design and fabrication process. The exploration through the case studies is centred around the creation of physical objects inspired by an iterative feedback loop between the material, designer and a six-axis industrial robot. The pedagogical approach includes an emphasis on learning-by-design for various computing tools, and their interaction and feedback with the 6-axis industrial robot with a focus on the connections between design intent, computational logic, and physical realisation.

2. ARCHITECTURE HISTORIC DIVISION

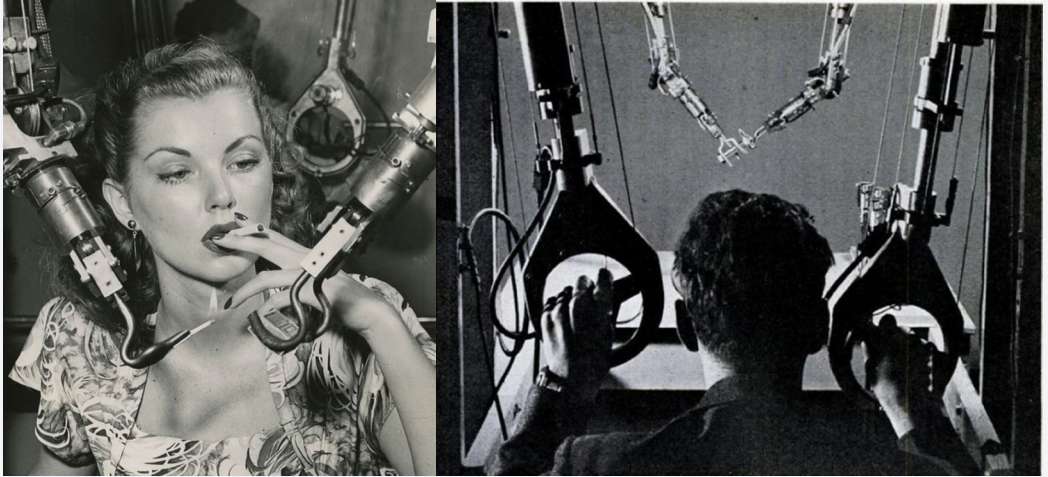
Since the Renaissance - some consider it to have happened during the 12th Century (Lloyd Wright 1901) - architecture has seen a division between intellectual work and manual production. Leon Battista Alberti's description of the architect in his influential treatise *De Edificatoria* makes a very clear distinction between design knowledge and instrumental knowledge, where the former defines the profession of the architect and the latter that of the builder (Witt 2010). For the last 500 years this method of designing and building remained unchanged (Sheil 2010). Architects designed and prepared drawings, which evolved through the engineers and other specialist analysis to end up fully detailed and costed. Buildings were built, forcing materials into form, corresponding as closely as possible to the original drawings. There were architects who disrupted this relationship, such as Jean Prouvé, Charles and Ray Eames, and designers at the Bauhaus, who brought machines to architecture, embedded with the idea of having machines in one's atelier to test (Feringa 2015). These visionary architects reinforced the idea that while architects are not builders, they cannot remain isolated from the problem of building. They pioneered efforts in rethinking the relationship between design and making in architecture. Computers gave architects a new tool for the study and creation of form. They introduced the ability to create and manage greater complexity than that which could be managed



▲ Figure 1 Building Site of the future (2000) as envisioned by Villemard in 1910. Source: www.paleofuture.com

manually (Lynn 2008). Virtual models allowed new freedoms, but some of these forms could only be pursued at great expense. Robots introduce a new technological possibility to architecture, a displacement that provides a new frame of reference, new expectations, and new consciousness. This new potential is not only about technology but more importantly about changing the relationship between thinking and doing (Speaks 2011). It shifts the production conditions towards making manufacturing a continuation of the design process.

Jean Baudrillard asked: *“How can automation be smart if it makes us simple spectators?”* (Baudrillard 2005). Similarly, the French painter Villemard in 1910 depicted the construction site of the future as one where the architect is seated outside pressing buttons while the machines are building a brick wall (figure 1). Research and experimentation in digital fabrication seems to be approaching that scenario, moving the architect into the role of a mere spectator, an outsider button-presser. Hence, there is a need to develop a framework for robotic-aided fabrication that allows us to redefine the role of the architect in a world where computers consistently conduct higher levels of optimisation and machines are constantly capable of higher levels of complexity in materials and construction (Greyshed 2014). In particular we need a framework that allows the robot, in collaboration with the designer and the material, to create a difference that is meaningful. The proposed framework for robotic-aided fabrication includes various steps: the architect first designs and brackets the realm of possibilities of the material through digital and physical simulations. Later, during the deployment process, the design and material are continuously analysed, using 3D scanning and robotic vision technologies, informing each other through an interactive human-robot symbiotic process that brings design and making closer, thus rendering this division obsolete.



▲ Figure 2 Payne manipulator. The robot is only following instruction from a set of arms in another room. Source: <http://cyberneticzoo.com/>

3. SYMBIOTIC PARTNERSHIP

A human-robot symbiosis is different from the human-robot systems currently permeating architecture research laboratories and schools (Gramazio et al. 2014; Picon 2004; Gramazio & Kohler 2008). Creating this kind of interaction requires a creative design approach that takes into account the designer's needs, material criteria, and machine possibilities, especially as it involves appropriating a machine that has neither been developed nor optimised for use in architectural tasks.

Traditional symbiotic partnerships between human and machine, as laid out by J.C.R. Licklider in 1960, involve “men setting the goals, formulating the hypothesis, determining the criteria and performing the evaluations, while the machine does the routinizable work to prepare the way for insights and decisions” (Licklider J.C.R. 1960). He already anticipated that through these symbiotic partnerships man would be able to perform intellectual operations more efficiently than alone.

During the 1960s with the advent of computational systems, ideas emerged in architecture regarding how these new methods could allow architects to give some control over the design to the end-users, allowing them to shape their living environments (Vardouli 2013). These ideas were reflected especially in the works of French architect Yona Friedman and the Architecture Machine Group at the MIT. They raised questions about authorship and performance: who performs the design? After an initial era of robotic experimentation in architecture, architects have gained a better understanding of the machine and material processes such that similar questions regarding the machine and its implications for the design model can be asked. In this case, it is not for a non-expert-centred model, as in the 1960s, but for one that redefines the roles and skills of experts in a design process wherein robots can overcome being used only as new building machines and become agents in a participatory fabrication process.

4. DEFINING THE ROBOT

There are many kinds of robots with great potential uses in architecture. For the context of this paper, “robot” refers to a six-axis industrial robotic arm. Industrial robotic arms

have been in use in the industry since the 1960s. They are a proven, robust, off-the shelf platform that is flexible enough to accommodate the needs of the designer (Braumann & Brell-Çokcan 2012). Robots differ from other numerically controlled machines such as CNC-millers and CNC-cutters that are digitally controlled versions of well-established processes. Robots are generic pieces of hardware (Menges & Beesley 2014) and only become specific through custom-designed and built end-effectors. In this scenario, the designer does not need to concentrate on the design of the robot but on the design of the end-effector or tool that the robot will use and, more importantly, can focus on the design of the process.

The main human-machine interface for robotic arms is the teach pendant. Through the teach pendant it is possible to: control the rotation and position of each of the joints, control the position and movement of the end effector, control the robot's movement and speed, and create programs. The pendant cannot be operated intuitively and the proprietary language of different robotic arms limits their user-friendliness (Lin & Lin 2014). Technological developments have allowed for sensors to be implemented as an alternative method to control the robotic arm through body movements. Although this allows for more intuitive forms of control, it can only be used for simple movements. Robots are not smart tools; they rely on offline programming sequences and will only do whatever they are programmed to do. Through the addition of sensors, 3D scanning technology and cameras we can equip them to become aware of their surroundings and react to certain conditions. These technologies can enhance the link between the digital data, the designer's intentions, and the material behaviour. At this stage, robots are not able to make decisions by themselves in settings like construction sites or in the design process. The development of a real human-robot partnership becomes crucial, as humans are better equipped to make judgement calls while robots can consider the whole picture and carry out analysis.

5. AGENTS

There are various definitions of agency and what an agent is. However, the preferred definition for this paper is that from Michael Callon and Bruno Latour who define an agent as *"any element which bends space around itself, makes other elements dependent upon itself and translates their will into a language of its own"* (Callon & Latour 1981). A description of the different agencies and their potentiality is presented before any relationship is formed.

5.1 Robotic Agency

Designing and using robotic agency rather than using the robot as just another fabrication tool requires an introduction of scientific rigour to the design process; a holistic approach to architectural design that considers adaptivity; a set of organisational principles, material, and machinic processes and a mutually formative relationship between cultural and technical aspects. This implies the introduction of a technological basis for architecture, which has remained relatively elusive when compared to other disciplines (Willmann 2015). Using a robot forces architects to think systematically about what they are doing and to mechanise the complexity of craft and other manual tasks, which are normally taken for granted.

The role of the robot in architectural processes is still ambiguous. Four scenarios are envisaged that allow for different degrees of robotic participation in the design process:

- As a slave to the designer's wishes, as can be seen in most robotic applications in architecture today: the robot only obeys human orders;

- As an amplifier that does not simply replicate the designer's wishes, but can elaborate upon them and contribute technical expertise towards the design intentions (Negroponte 1973); this would be a human-robot symbiosis: the robot would guide the designer's decision making according to a complex set of local and global criteria that might have been ignored otherwise;
- As a coordinator or regulator where robots make alternative decisions in human situations, as they can have a more comprehensive perspective, using their computing ability to process large amounts of information (Lem 2014); the robots only provide advice and it is the humans who make final judgement calls: this perspective merges the computing strength of the robot and the perceptive strengths of the human;
- As a consultant, who is called upon to help even if it does not agree with the personal premise of the designer (Friedman 1980).

Robotic-aided fabrication aims for a scenario in which robots enhance human creativity by giving designers an insight into their own creation and materialisation process. The degree of agency they have in the process will be defined at the point where architecture absorbs this new connection between computational logic and material realisation.

5.2 Human Agency: The Role of the Architect

Humans are constantly immersed in a physical world. Human agency is then regarded as a subjective first-person perspective on one's way of reacting to and acting within the world (Malafouris 2008). Professional identities in architecture are diverse and dynamic. The role of the architect has varied throughout history- from the poet master-builder that frames all other arts inside his edifice (Lloyd Wright 1901) to the virtual master being recognised and acknowledged through objects that exist only on the screen (Loukissas 2012). The boundaries of architecture are continually shifting (Schon 1984). A comprehensive, traditional definition will be that of the architect as a "generalist" who needs the capacity to deal with and negotiate amongst different specialists, consultants, and clients, and achieve enough understanding to allow the execution of a design vision. The ubiquity of computers, simulation, representational and generative software and their increased use in architectural practice has convinced an increasing number of architects to give up their position as generalists in favour of establishing islands of expertise (Schon 1984) that span the areas of coding, geometry specialists, CAD managers and BIM consultants.

Computers have become central to the architectural workflow, increasing connectivity and enabling collaborative modes of practice between architects, engineers, and specialists. Additionally, they have blurred further the already ambiguous boundaries that separate architects from engineers (Loukissas 2012), since both now use the same simulation and coding tools. As the divide becomes unclear, new common fields for negotiation and discussion are created. Digital technologies and geometric modelling further challenge traditional views of architecture as an unmediated representation of the will, knowledge, and intuition of the architect. They redefine the traditional master-apprentice relationship considered central to architectural practice and to design education (Schon 1984; Cuff 1992; Picon 2010) –a situation that is still polemical and even conflictive for some architects, who feel that seeing the computer as an intelligent tool diminishes their knowledge.

5.3 Material Agency

Material agency is a concept introduced by Lambros Malafouris in his essay, "At the potter's wheel" in which he challenges previous anthropocentric notions of agency by defining it as follows: "If there is such thing as human agency, then there is material agency; there is no way human and material agency can be disentangled"(Malafouris 2008). He goes on

further to describe material agency as something not inherent in the material itself, but as a relational, emergent property that develops through engagement with the material, as can commonly be seen in craft processes, and one that is characterised by continuous dances of agency, resulting from the coupling of mind and matter.

The concept of material agency has recently entered the architectural discourse (Picon 2004; Gramazio & Kohler 2008). Alberti once said, *“It is quite possible to project whole forms in the mind without recourse to the material”* (Alberti 1988). In architectural practice, materials have traditionally been used to construct a built version of an idea that was determined in advance. Designs after conception are subjected to complex processes of rationalisation where tension occurs between the material and the form due to the initial disassociation between them. Additionally, designs usually follow their initial path, disregarding any information that the material might have been trying to add during the formation process. This has resulted in a linear, unidirectional flow of information from design model to code to robot. (Bechthold 2010)

New developments in 3D scanning technology such as Kinect and cloud scanning applications (e.g., Autodesk 123D Catch) have made movement between the digital and the physical easier. These applications allow the analysis and simulation, and experimentation with material properties, and of new material configurations to be better and faster than ever before. By giving us a deeper understanding of material behaviour, they allow craft as an approach to making rather than as a specific way of making (Sennet 2009) to become an active agent during the design and materialisation process. In this context, craft and material agency refers to form being developed following the potentials of the material rather than it being conceived by the architect and then imposed on passive matter (Protevi 2005).

6. SHIFTING THE AGENCY MODEL

The use of novel digital technologies in architecture represents a challenge to the traditionally accepted divide between “two cultures” (Snow 2012) or two ways of thinking: the qualitative culture generally dominant in the arts and humanities, and the quantitative culture usually related with science and technology. The architect needs to start from an understanding of design and making, negotiating and merging them into a holistic process in which the division between the one and the other is no longer visible. This leads to the creation of an architectural process that regards robotic technology not only as another production medium but also as its cultural interface (Willmann 2015).

Understanding the implications of robotics in architecture requires a broad view of how they affect the system and its relationships. It requires integrating the parameters and principles of the robot with the material intelligence and human agency on site. Robotic fabrication allows the designer to get *“closer to the analogue and material world by mastery of the digital world”* (Sheil 2012) through an iterative process between the two worlds. It establishes a new paradigm in which a deep crucial relationship between architecture, technology, and its physical materiality is enabled by new modes of machinic thought. The architect becomes a designer of processes and interfaces between the virtual and the physical, and an editor of constraints for their interactions. The robot becomes the coordinator that can oversee the whole project, guiding the process of formation, in which the architect makes the final judgement calls.

Matter and material behaviour are implicated in the geometry itself (Reiser 2006). The architect brackets the realm of possibilities by embedding design principles in the

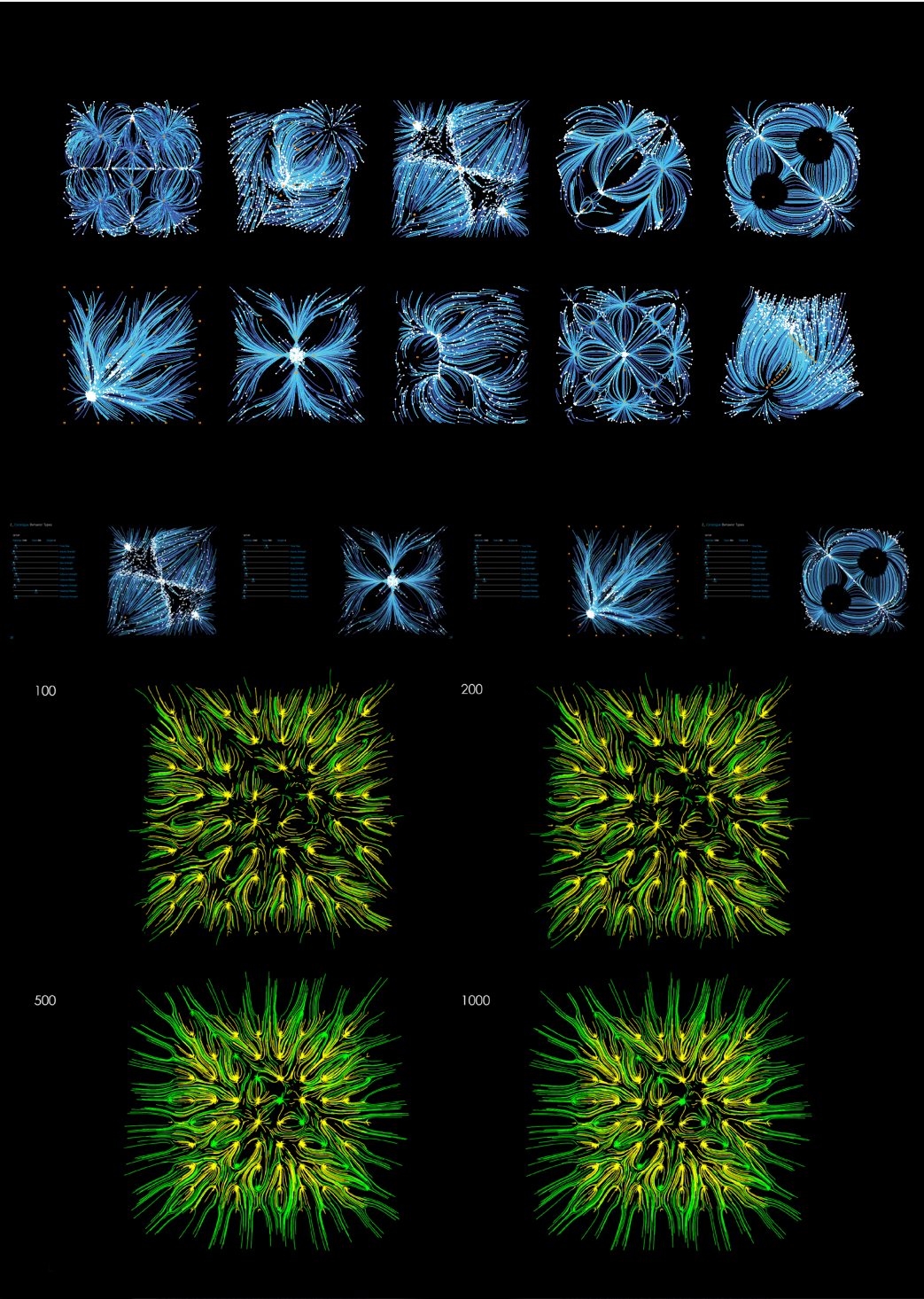
material and using constraints that open new possibilities during the formation process. 3D-scanning technologies and robotic vision then capture the complexity of these phenomena and present them to the architect and the computer to analyse before the next move. This process differs from cybernetic attempts in the early 1960s that were very open-ended towards the user input. Here the machine has a defined human goal that it is trying to achieve.

As the new architectural process finds its place, the other agencies involved in the building process will adapt. Architects will have to find which sphere they can occupy in this new ecosystem of tasks and agencies. In the current state of robotic-aided fabrication, architects are conducting material research, robotic research, geometric design, and are also designing their interactions. This situation will not continue indefinitely. Engineers, contractors, regulators, builders, and consultants will also have to find their roles and the robotic process will need new expert roles to be created. Architects will need to reframe their work and skills around these new agencies and negotiate this technological moment, which is changing the human-machine-material relationships. Similar to the revolution initiated by computers when introduced to architectural practice, the profession has largely never looked back [Cecchi 2015]. The new machine suggests now as it did then: *“a new range of forms, new ways of knowing and new kinds of professionals in architecture”* [Loukissas 2012]. Robots are changing the discipline, redefining its relationships and boundaries, similar to other disciplines like physics; the first experimenters struggle to position themselves within the established categories until eventually altering them [Galison 1997].

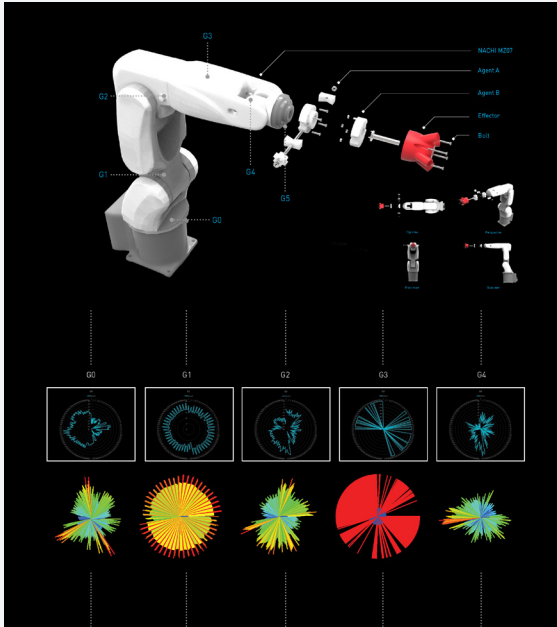
“Strange Strangers” is how Timothy Morton describes the relationships between entities. He says that the information at the moment of interaction between agents is always incomplete, suggesting that the outcome will always be unexpected [Morton 2012]. Designers like to design, to be in control of all aspects of their creations. A shift in the agency model encouraged by new digital technologies requires the designer to relinquish some of his unidirectional control, and allow the unknown control of matter to develop during the process of becoming [Pickering 2011]. This process raises questions of authorship. A new mode of non-authorship should arise similar to that of Gothic cathedrals, where the interaction between the agents was paramount. Novel hybrid-agency models, in which the architect becomes an active agent through the materialisation process and diverse agents have equal influence on the final design will be required [Carpo 2011].

7. CASE STUDIES

The following three case studies have been selected to illustrate a range of design interactions that the authors organized and investigated between human and industrial robots during the design process. The interaction in each case is positioned on different parts along the design-fabrication continuum, offering an opportunity to study and speculate on different approaches to human-robot symbiosis in architectural practice. The case studies were setup in a way that allows for identifying the potential productive connections between materials, machines, code, and humans. The role of the architect throughout the different case studies is that of an active designer of the system and of the rules for the other actors to operate upon. As an active designer, he brackets the possibilities of the system through the different stages based on an analysis of the behaviours of the other agencies. The last two case studies address material variation as a creative force [DeLanda 2004] that allows us to incorporate difference and feedback during the fabrication stage. By studying them, we can identify the skills and toolboxes that define the new role of the architect as an active agent during the design and fabrication stages.



▲ Figure 3 Catalogues of generative design patterns from particle system behaviours and their parameters



▲ Figure 4 Top: Design of end effector. Bottom: Analysis of movement of each robot axis for optimisation.



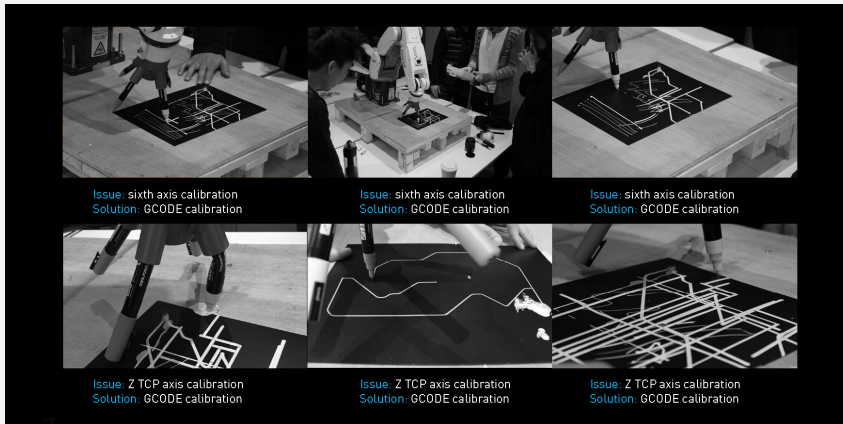
▲ Figure 5 Physical robot setup. Team 1

7.1 Instructing Machines

A three-week workshop was taught in collaboration with Shajay Bhooshan, Vishu Bhooshan and David Reeves at the Architectural Association Design Research Laboratory M.Arch (AADRL), London, UK.

The case study “*Instructing Machines*” was run in November 2015 with AADRL graduate students. The focus of the workshop was to introduce code as a generative tool to instruct machines such as the computer and the robot and to analyse their output. It started with an introduction to the C++ language as a generative tool for designing patterns based on attraction-repulsion particle behaviours. After experimenting with this, the next step was choreographing the robot behaviour with the geometric moves by generating the G-Code from this same platform. Students worked in teams and the workflow included: generating the particle system, understanding the parameters and behaviours of particle forces, learning the constraints of the robot, incorporating them into the generative code, and finally converting the result into a set of points which could be followed in the physical world by an industrial robot. Students had the option of using the robot for either drawing or stippling their set of points onto paper. A Nachi MZ-07 6-axis industrial robot with a 7kg payload was used.

One of the initial facts that became evident when students were introduced to a robot arm for the first time was that, contrary to other machines that have a defined use, a robot arm cannot do anything without designing its tool or end effector. Students had been told to use it for drawing or stippling, so the first task was to design a tool that could handle a marker or a needle. Secondly, given the number of tasks that a robot arm can perform, its movements can be optimised in multiple ways. Its inverse-kinematic system can reach the same point in many possible configurations; some of them can be better for speed, for load, for torque, etc. For some points there can be multiple, nearly infinite, numbers of

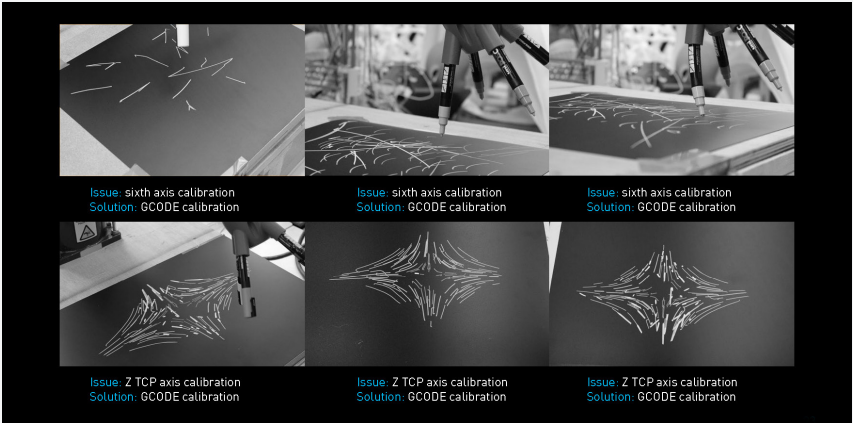


▲ Figure 6 Robot instruction, analysis and calibration

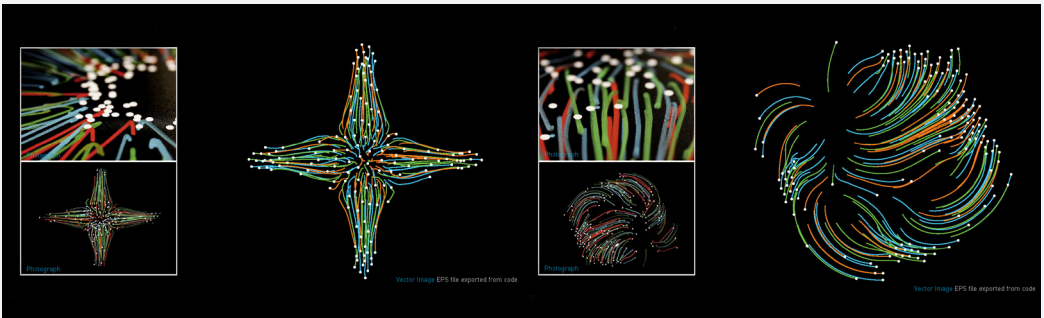
solutions. There is also the possibility of zero solutions if the point is out of the workspace or at an impossible angle for the end effector. Without a defined tool, a single optimisation procedure and the possibility of multiple solutions for the same task, the designer is forced to think about the steps and the final result that he wants to accomplish in order to decide how to plan its motion, generate the code, and optimise its output.

The Nachi robotic arm, unlike other robot brands, compiles its code directly in the software and not in the controller so a live link can be established. This means that changes to the robotic path can be made directly from the computer. The pre-developed design program that the students were using combined the generation of the particle simulations and the generation of the G-Code for the robot inside the same software platform. This meant that changes to the attraction and repulsion forces of the particle system, and hence to the drawing pattern became immediately apparent as changes to the robot movement trajectories. This direct relationship between pattern generation and the robot's movement meant that the design and its physical representation were directly connected. The designer becomes an editor of the generative parameters of the system, as set out at the beginning, and hence of the output, without directly designing the final product, but by controlling the digital and physical parameters for its generation.

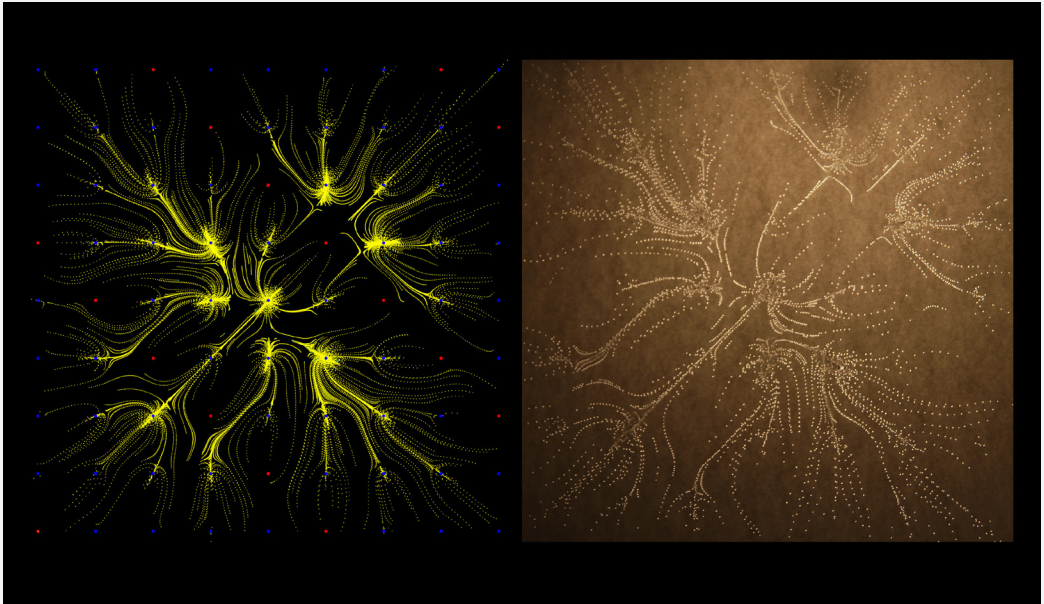
During the process of converting the pattern to a set of points that could be used by the robot and that represent the designer's intentions, a set of additional parameters had to be introduced to the code such as: Z-values for the robot to lift after each point or at the end of the lines so they are not continuous and indistinguishable, checking reachability to all the points, height and rotations of the designed end effector, analysis of the number of points in the digital pattern versus the necessary ones in the physical world to optimise machining time, speed of the robot, and more. The students were able to achieve this via intensive collaborative working in the studio that allowed rapid generation of patterns, immediate access to the robot for testing, and continuous access to manual jogging of the robot to understand its behaviour with regular tutor support. During the 5-day production phase of the workshop, 14 students generated over 30 physical drawings in a continuous evolution of forms. The final outcome allowed students to explore forms of design and creation using an industrial robotic arm, to understand the potentials of the machine and to realize that a series of parameters has to be considered from the early stages to have a successful, strong, direct connection between design parameters and physical output.



▲ Figure 7 Setup for Robotic drawing of the generated patterns

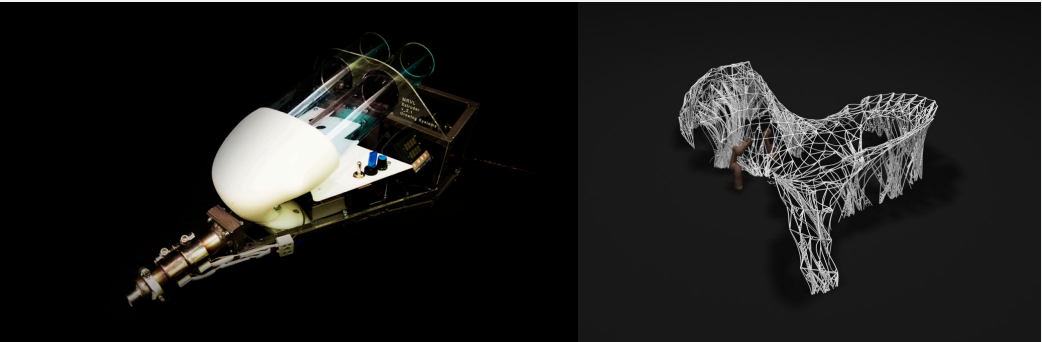


▲ Figure 8 Photographs of robotic drawings from generative patterns.

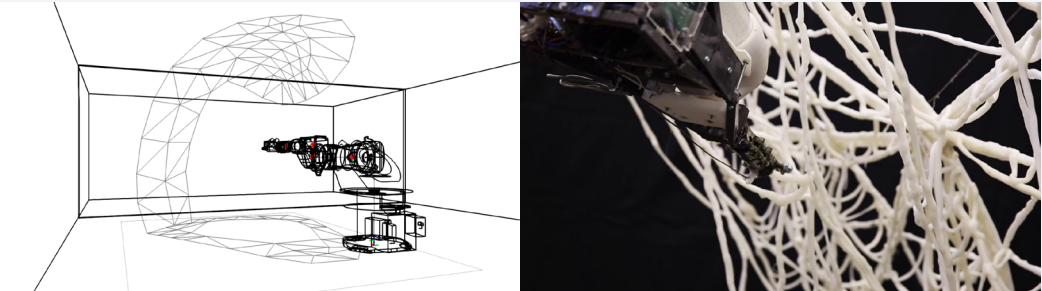


▲ Figure 9 Photographs of stippled robotic drawings from generative patterns.

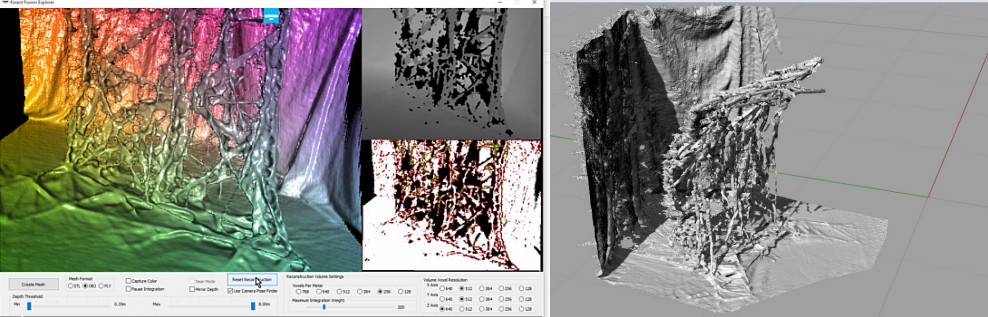
All figures from AADRL, 2015. Instructing Machines workshop.



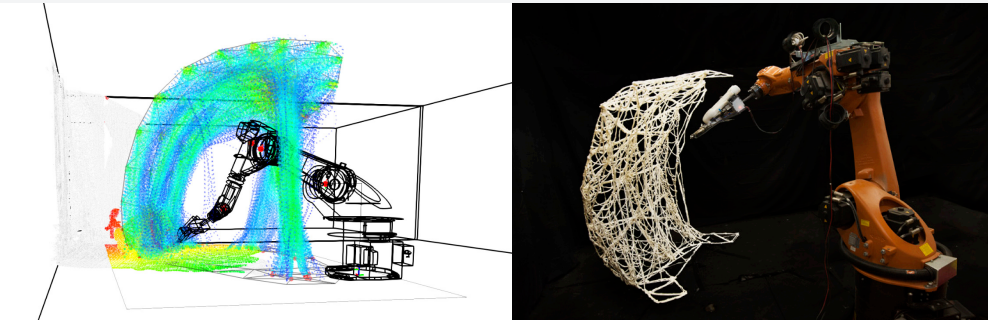
▲ Figure 10 Left: custom-made end-effector. Right: Generative design system based on multi-agent behaviour



▲ Figure 11 Left: Initial path setup. Right: Extrusion detail



▲ Figure 12 3D scanning using Kinect for robotic path recalculation and for calibration between physical and digital models.



▲ Figure 13 Left: re-computed tool paths based on deposited material. Right: Built prototype of spatially extruded polymorph plastic. 1.8m tall. All Figures from Team MRVL, Studio Bhooshan, AADRIL 2015

7.2 MRVL Plastic Spatial Printing:

A collaboration with Studio Bhooshan from the Architectural Association, Design Research Laboratory. M.Arch (AADRL), London, UK.

MRVL is a team of 4 students from Studio Bhooshan at the AADRL. In December 2015 during the final stages of their 16-month Masters program, they worked with the first author as an observer and robot consultant to their fabrication process. The focus of the design lab is in developing prototypical construction methods that allow describing, evaluating, and searching for the right designs using robotic industrial arms (Architectural Association 2015). The team designed and developed a custom-made end effector for a 6-axis industrial robot to spatially extrude polymorph plastic in a collaborative fabrication process. Polymorph plastic traditionally comes in granules that look like small beads.

The team developed a design system based on topology optimisation and multi-agent generative design principles. The system, following the rules established by the designer, generates different configurations of architectural space, providing the positions of main and secondary structural members. These are then transformed into paths for the robot to extrude / deposit plastic. The purpose-built end-effector heats the pellets to 90 degrees before starting extrusion and has sensor controls to prevent overheating.

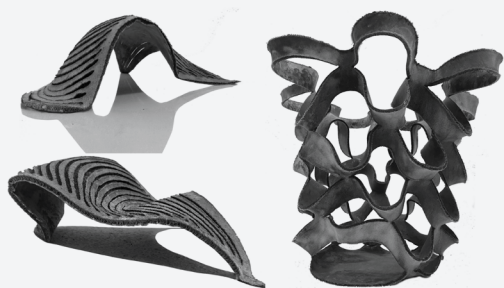
The specific characteristics of the material make it shrink slightly after extrusion. This, combined with the precision of the robotic arm, which cannot adjust on its own to the varying shrinkage, necessitates the introduction of a robotic vision system in which each path is scanned after deposition. Information obtained from the 3D scan is then fed back to the original design model in order to calibrate the digital and the physical, analyse the geometry, and re-compute the next extrusion path to ensure that all structural members are connected with each other. A system in which the robot becomes an agent responding to previously extruded plastic is created.

The process requires extremely active participation on the part of the designer during the fabrication stage. As opposed to traditional robotic fabrication processes, in which all the instructions are sent to the robot at the beginning, the setup feedback loop requires the robot to ask the designer after each path where to go next. For each path, the robot needs to keep the form-optimisation while avoiding already deposited material. As the form builds up, it becomes more densified, so the robot's awareness of its environment is crucial. A semi-autonomous system is created, in which the robot can keep to the next path as per its analysis based on the scanned information and re-computation of the system, or the designer can provide a different solution based on his or her qualitative analysis and overall design intent. As the design adapts to the environment and responds to previously extruded plastic, it is continuously changing during the fabrication process. The final outcome can have several degrees of variation from the initial input, hence the importance of the designer's active presence during the process to control variation and adapt both the digital model and the physical model through the robot. During the 4-day production phase at the Welsh School of Architecture, the team built a 1.8-meter-tall prototype with a weight of 25kg. The robot printing time was 12 hours.

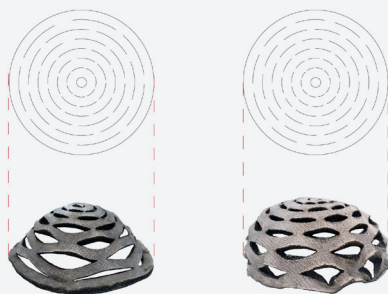
7.3 Pop-Up Concrete:

On-going research project developed by the author at the Welsh School of Architecture.

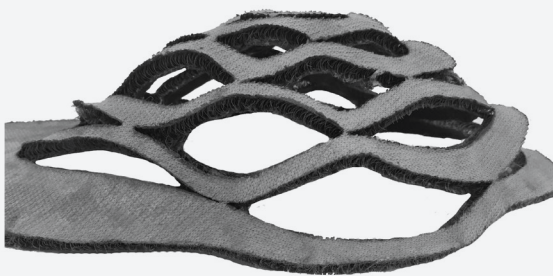
Flat packed, pop-up concrete structures are explored as a means to create a flexible and adaptable fabrication system for the creation of thin-shell, medium-span complex concrete



▲ Figure 14 A vocabulary of pop-up structures is starting to develop, as a result of the design process



▲ Figure 16 Changes to the cut and joint pattern with boundary conditions and relaxation constant show different results after inflation

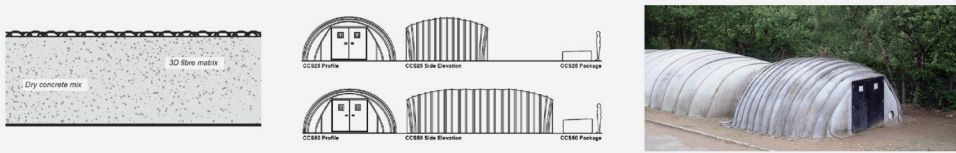


▲ Figure 15 Left: 2D pattern laser cut in concrete canvas. Right: Popped - up concrete canvas shell prototype

structures, furniture, and complex leave-in formwork for larger structures. For this process, Concrete Canvas, a new material technology, is explored due to its hybrid characteristics that blend fabric and thin-shell tectonics. The focus of the research is to develop novel construction systems that integrate with the current robotic and architectural discourse. The digital workflow includes: pattern design; digital simulation; on-site cutting and inflation through a collaborative, iterative, material feedback loop; structural analysis; and hydration of the final shape. It allows the designer to manipulate concrete structures on-site, as informed by structural analysis, designer input, and their own choices.

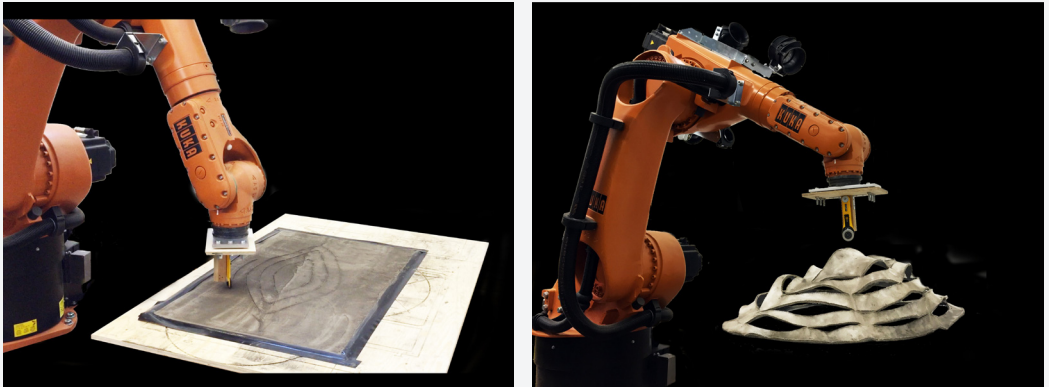
The popped-up geometries are based on a parametric system of 2D cutting patterns performed in 'concrete canvas'. The 2D patterns transform into extended 3D surfaces by lateral buckling induced by spatially non-uniform growth during the phase-changing period of the material. The system setup is initially done both physically and digitally, so that when the units pop up they inform and calibrate each other through an iterative feedback loop. A pattern gets embedded in the material so that, when it pops up, it is capable of a range of configurations that are structurally stable while also achieving qualitative architectural effects. Fabrication, in this system, comes from embedding transformative capacities in the material, rather than from transferring the form directly from the computer into the material as in traditional unidirectional fabrication processes.

Beyond the optimization criteria and parametric setup, the system focuses on collaborative design as a way to approach material exploration through robots. Typically, the outcomes of a fabrication process are predetermined. However, the introduction of a 2D cutting



▲ Figure 17 Left: Concrete canvas section. Middle: Typical deployment sequence. Right: Shelter structure.

Source www.concretcanvas.com

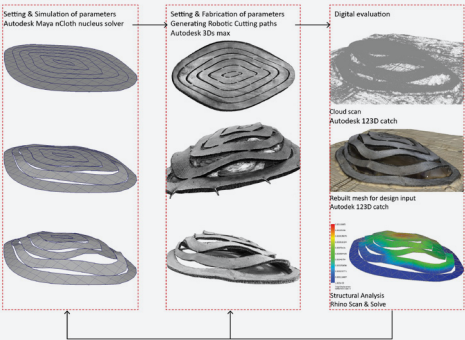


▲ Figure 18 Top: Setup and end effector for robotic cutting of concrete-impregnated fabric. Bottom: 1.0x0.7x0.7 popped-up prototype.

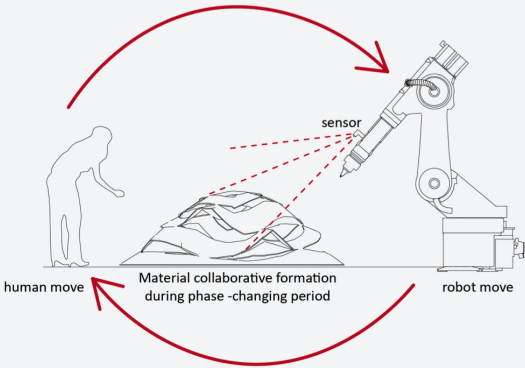
pattern within a concrete phase-changing material system over a pop-up process allows for several configurations to be created through a collaborative design and fabrication process. The feedback loop between designer, material, and robotic production creates negotiation opportunities that result in a rich and complex design process with many intelligences: human, the algorithms embedded in the design, and the material.

Concrete Canvas, as a material, allows for experimenting with new uses for concrete. It is composed of a layer of dry cement with its reinforcement impregnated between two sheets of fabric. In its dry state the material can be formed and worked as malleably as fabric, but when hydrated it becomes very rigid, acquiring the stable properties of concrete. Given this duality, the behaviour of the material is probable, but not certain. This characteristic allows one to assess the structural influence of the patterns of cuts and joints and the effects of its variations during the pop-up process. The system uses inflation to pop up into a surface. Once a satisfactory shape is achieved, the concrete is hydrated, allowing it to cure and become structurally rigid.

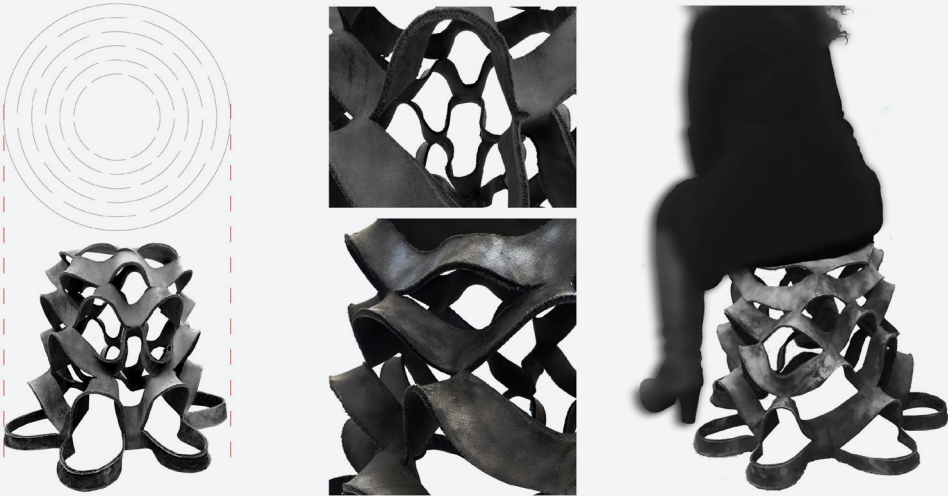
Using new digitisation technologies, the popped up shape is scanned and taken back to the computer for structural analysis and calibration with the digital simulation and for design refinement. With this information, the designer can continue modifying the inflation until equilibrium between material, structure, and form is reached. Finally, the concrete is hydrated and left to settle for 24 hours. A feedback loop between the digital and the material is created and continuously updated during the form-finding and form-making processes. The aim of the system is to provide a production technique for the quick



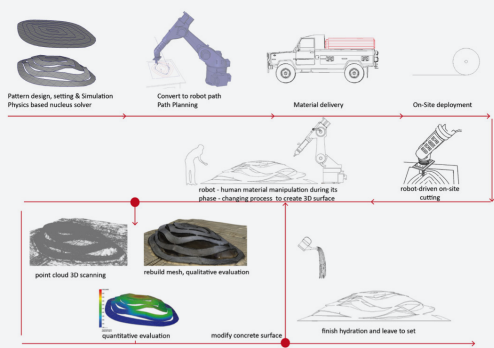
▲ Figure 19 Diagram showing the workflow set out and feedback loop



▲ Figure 20 Designer-robot -material negotiations during the formation, or pop-up process, of the material



▲ Figure 21 Left: 2D pattern and resultant 3D geometry. Middle: Concrete details. Right: Live load testing of prototype



▲ Figure 22 Envisioned fabrication scenario, including path planning workflow and feedback loop

deployment of shell structures, where modelling, analysis, and fabrication are integrated. Form in this process emerges as a result of a negotiation amongst structural, material and design constraints.

The generation of pop-up structures is not random, but caused by set boundary conditions of the embedded cut and joint pattern, and follows precise physical principles during its pop-up. Through the feedback loop and with defined boundary conditions, the results can indirectly be controlled and emergent shapes can be created by stopping the process at any point in time during the pop-up phase of the concrete. 3D pop-up geometries can achieve a space-enclosing surface faster than 3D printed ones.

In this case, as opposed to that of the previous one, the designer constrains the possibilities of the system through the design of the cutting pattern and the properties of the concrete fabric. During the pop-up process, decisions can be made that favour different final configurations. This variation is bracketed to the realm of possibilities allowed by each cutting pattern initially defined and simulated by the designer. This kind of approach changes the role of the architect to that of an editor of constraints and a designer of a system through the material and the machine, rather than that of a designer of the final product.

8. DISCUSSION

The case studies show how using the symbiotic agencies of the robot, the designer and the material allows us to explore opportunities to create new aesthetic languages for our built environment. The interaction between the robot and the designer can happen at different stages of the design, from very early phases as in the first case study, up to the final delivery of the design, or during its construction as shown with the pop-up concrete and the plastic deposition examples. In these last two cases the iterative fabrication process leads to a sentient material that engages, through the robot, in a design dialogue with the architect.

Experimenting with materials as per case studies 2 and 3 proved to be an immersive and fascinating field very easy to get lost in [Hale 2013]. Keeping in mind that the main objective is searching for new modes of practice and connections between the different agencies allows us to speculate ways in which architects can redefine their role while maintaining a vital connectivity to the multiple forces, acknowledging the importance of the different actors: technique, geometry, material, and machine, to their designs. This shift represents challenges for architecture that open new formal and epistemic opportunities [Witt 2010]. In these envisaged scenarios, architects are no longer designing buildings and its works but rather designing performances between human and non-human entities, editing their constraints, relationships, and the environments in which they evolve through the use and invention of new machinic and non-machinic agencies that operate in the physical world.

9. CONCLUSIONS

The current status of robots in architecture is that of providing a new sense of 'intimacy' between the designer, his or her tools [Willmann 2015], and materials similar to those which painters and sculptors have enjoyed, yet with the precise digital control. This control is achieved through the use of sensors and vision technologies guided by the machine. The exactitude of variation during the materialisation process is new to the architectural designer. However, concrete, larger-scale industrial applications of robotics in architecture are still missing.

Robots support a new multidisciplinary approach to design, encouraging architects to work directly from early stages with engineers, materials scientists, and electric engineers providing a more holistic approach to construction. They allow architects to mix craft and tools in an intellectually meaningful way, creating a trinity of material, technology, and form (Lynn 2008). The usage of a robot, its limitations and constraints has to be considered from the beginning. This requires the incorporation of specific thinking during the generative design stages, as shown through the case studies. However, robots are only one part of the construction process, and in some cases the robotic part can further complicate downstream and upstream processes. Robotic fabrication needs to be able to handle a continuum of inputs and outputs feeding into each other. The methods in which robotic processes integrate with the rest of the construction site, and in which robot-human choreographies can be measured and adapted to the different routines needed during the on-site life of a project, are enormous areas for exploration.

These case studies demonstrate a number of proof-of-concept human-robot collaborations for robotic-aided fabrication. This design agenda involves not only human-robot interaction, but also robot-robot interaction and the development of a range of robotic and multi-robotic choreographies and their orchestration. Robotic-aided fabrication holds the potential for rethinking the role of the architect in the design and fabrications process. It allows for the creation of a new professional role for the architect that combines critical thinking whilst taking advantage of new tools and agencies interacting collaboratively to create greater designs that would be nearly impossible otherwise. In its current status, it encourages performative dances of agency without a defined centre.

REFERENCES

- Alberti, L.B., 1988. *On the Art of Building in Ten Books* J. Rykwert, N. Leach & R. Tavernor, eds., MIT Press.
- Association Architectural, 2015. AA Prospectus 2015-16, Available at: <http://www.aaschool.ac.uk/APPLY/PROSPECTUS/prospectus.php>
- Baudrillard, J., 2005. *The System of Objects*, Verso Books.
- Bechthold, M., 2010. 'The Return of the Future: A Second Go at Robotic Construction.' *Architectural Design*, pp.116–121.
- Braumann, J. & Brell-Çokcan, S., 2012. 'Digital and Physical Computing for Industrial Robots in Architecture'. *Beyond Codes and Pixels: Proceedings of the 17th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA)*, pp.317–326.
- Callon, M. & Latour, B., 1981. 'Unscrewing the Big Leviathan'. In A. V. Cicourel & K. D. Knorr-Cetina, eds. *Advances in Social Theory and Methodology: Towards an Integration of Micro- and Macro-sociologies*. Routledge & Kegan Paul PLC, pp. 277–303.
- Carpó, M., 2011. *The Alphabet and the Algorithm*, MIT Press.
- Cecchi, N., 2015. *Procedural Geometry: An Interview with Aranda\Lasch*. Archinect. Available at: <http://archinect.com/features/article/141844613/procedural-geometry-an-interview-with-aranda-lasch> [Accessed January 6, 2016].
- Cuff, D., 1992. *Architecture: The Story of Practice*, MIT Press.
- DeLanda, M., 2004. 'Material Complexity.' In N. Leach, D. Turnbull & C. Williams, eds. *Digital Tectonics*. Wiley Academy, pp. 14–21.
- Feringa, J., 2015. *laaC lecture series*.
- Friedman, Y., 1980. *Toward a Scientific Architecture*, MIT Press.
- Galison, P., 1997. *Image and Logic: A Material Culture of Microphysics*, University of Chicago Press.
- Gramazio, F. & Kohler, M., 2008. *Digital Materiality in Architecture*, Baden: Lars Müller Publishers.
- Gramazio, F., Kohler, M. & Jan Willmann, 2014. *The Robotic Touch: How Robots Change Architecture*, Park

Books.

Greyshed, 2014. Workflows for Augmented Materiality. Bartlett International lecture series 2014/15. Available at: <https://vimeo.com/116766943>.

Hale, M., 2013. 'The Architect as Metallurgist.' In H. Frichot & S. Loo, eds. *Deleuze and Architecture*. Edinburgh University Press, pp. 111–130.

Lem, S., 2014. *Summa Technologiae*, University of Minnesota Press.

Licklider J.C.R., 1960. Man-Computer Symbiosis. *IRE Transactions on Human Factors in Electronics*, HFE -1, pp.4–11.

Lin, H. & Lin, Y., 2014. A Novel Teaching System for Industrial Robots. *Sensors*, (ISSN 1424-8220), pp.6,012–6,031. Available at: www.mdpi.com/journal/sensors.

Lloyd Wright, F., 1901. 'The Art and Craft of the Machine.' *Brush and Pencil*, 8(2), pp.77–81, 83–85, 87–90. Available at: <http://www.jstor.org/stable/25505640>

Loukissas, Y.A., 2012. *Co-Designers: Cultures of Computer Simulation in Architecture*, New York: Routledge.

Lynn, G., 2008. *Form*, New York: Rizzoli International.

Malafouris, L., 2008. 'At the Potter's Wheel: An Argument for Material Agency.' In C. Knappett & L. Malafouris, eds. *Material Agency: Towards a Non-Anthropocentric Approach*. Springer, pp. 19–37.

Menges, A. & Beesley, P., 2014. 'Achim Menges in Conversation with Philip Beesley.' In F. Gramazio, M. Kohler & S. Langenberg, eds. *Fabricate: Negotiating Design and Making*. gta Verlag, pp. 156–165.

Merleau-Ponty, M., 2013. *Phenomenology of Perception*, Routledge.

Morton, T., 2012. *The Ecological Thought*, Harvard University Press.

Mumford, L., 1959. An Appraisal of Lewis Mumford's "Technics and Civilization" (1934). *Daedalus*, Current Work and Controversies (summer, 1959), 88(3), pp.527–536. Available at: <http://www.jstor.org/stable/20026520>

Negroponte, N., 1973. *The Architecture Machine: Toward a More Human Environment*, MIT Press.

Pickering, A., 2011. *The Cybernetic Brain*, University of Chicago Press.

Picon, A., 2004. 'Architecture and the Virtual: Towards a New Materiality.' *Praxis: Journal of Writing+ Building*, (6), pp.114–121.

Picon, A., 2010. *Digital Culture in Architecture*, Birkhauser Architecture.

Protevi, J., 2005. *The Edinburgh Dictionary of Continental Philosophy*, Edinburgh University Press.

Reiser, J., 2006. *Atlas of Novel Tectonics*, Princeton Architectural Press.

Schon, D.A., 1984. *The Reflective Practitioner: How Professionals Think in Action*, Basic Books.

Sennet, R., 2009. *The Craftsman*, Penguin.

Sheil, B., 2012. 'Distinguishing between the Drawn and the Made.' *Architectural Design Special Issue: Material Computation: Higher Integration in Morphogenetic Design*, 82(2), pp.136–141.

Sheil, B., 2010. *Protoarchitecture. The Funambulist*.

Snow, C.P., 2012. *The Two Cultures* Reissue ed., Cambridge University Press.

Speaks, M., 2011. Lecture at University of Michigan, Taubman College. Available at: <https://www.youtube.com/watch?v=2ISnW0cuV5Y>

Vardouli, T., 2013. Performed by and Performative for Rethinking Computational Models for User Participation in Design. In *eCAADe 31*. pp. 243–252.

Willmann, J., 2015. 'The Otherness of the Machine.' *Cube Magazine, Uncanny Valley*, pp.38–44. Witt, A.J., 2010. 'A Machine Epistemology in Architecture. Encapsulated Knowledge and the Instrumentation of Design.' *Candida. Journal for Architectural Knowledge*, 03(03), pp.37–88.

Design-research by making: An educational hands-on approach to design-research through manual/ robotic processes

Ioanna Symeonidou & Renate Weissenböck

Institute of Architecture and Media, Graz University of Technology,
Austria

ABSTRACT

This paper presents educational experiences, linking analogue and digital design approaches. It suggests physical prototyping as a novel form of design research in an educational context, exploring design opportunities fostered by fabrication processes. The authors describe insights gained while leading two courses at Graz University of Technology, focussing on tactile experiments of forming materials, by hand or robots, guided by the material behaviour and reaction. Furthermore, this paper wishes to point out the advantage of research-based education, aiming for an understanding of design thinking that goes beyond curriculum and current technologies, fostering an open-ended development process.

INTRODUCTION

The unprecedented technological advances and paradigm shifts in design processes have had a strong impact in architectural practice, with a direct repercussion in education. With the rapid speed of new developments, there is an extensive discourse about the future of architectural education, with opinions converging to the belief that design education should be research-based, to keep up with current topics and technologies (Buchanan, 2001; Matthews and Buur, 2009; Simonsen et al., 2012). In the cases described in this paper, the authors combine design-research undertaken as part of their respective PhD dissertations with teaching concepts and methodologies developed during their teaching appointments at Graz University of Technology.

During the last decade, we have observed a strong tendency of linking the digital world to the physical-material realm. On the one hand, with the development of software that simulates physical behaviour, on the other hand, with the rapid development of digital fabrication techniques and interfaces, i.e. easy programming of industrial robots. In the age of digital fabrication, the role of architects in the design-to-build-process changes significantly, as they are able to extend their digital design competencies into the physical world, thereby gaining control over production and materiality. As Menges describes it *“A novel convergence of computation and materialisation is about to emerge, bringing the virtual process of design and the physical realisation of architecture much closer together, more so than ever before”* (Menges, 2012).

In our approach, we combine the advantages of the hands-on experience of the “Design-Studio” (Anderson, 2010) with the pedagogical approach and educational goal to provide students with special skills in design computation and fabrication, bridging design-thinking to analogue and digital making. In this “Research by Making” process, students explore morphogenetic strategies through digital and manual design experiments, with the aim to develop different kinds of sensibilities, intuitions and skills.

DESIGN RESEARCH

As constantly discussed in architecture conferences, Design Research still searches for identity and content. Groat and Wang, in their book *Architectural Research Methods* (Groat and Wang, 2001) tackle several of the issues regarding tools and methodologies for researchers. However, traditional structures of research do not prove effective any longer. New technologies not only affect the way we design, but they also seek for new paradigms in Design Research. Henk Borgdorff in the *Debate on Research in the Arts* claims that “Art practice qualifies as research if its purpose is to broaden our knowledge and understanding by conducting an original investigation in and through art objects and creative processes” and that “Research processes and outcomes are documented and disseminated in a appropriate manner to the research community and to the wider public” (Borgdorff, 2006). In that sense, there is no better research output than built examples to disseminate the results and findings of Design Research within the academia as well as to the industrial partners and local community. Design Research is a relatively young field, which suffers several “misunderstandings on the way to intellectual and practical strength” (Buchanan, 2001). Buchanan suggests that the origins of Design Research “may be traced to the early seventeenth century and the work of Galileo Galilei” and that “the creation of what Bacon calls ‘artificial things’—was generally ignored as a subject of learning, except to the extent that the design of instruments played a greater and greater role in the investigation of the natural sciences” (Buchanan, 2001). However, it was in the 1960’s that Design Research started gaining attention among several disciplines. The Conference on Design Methods at Imperial College London, in 1962, was the stepping stone that led to the founding of the Design Research Society (DRS) in 1966. Some years later, Herbert Simon paved the path for what he named the “Science of Design”, referring to “a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process” (Simon, 1996). According to Bruce Archer’s definition at the Conference of the Design Research Society in 1980 “Design Research is systematic inquiry whose goal is knowledge of, or in, the embodiment of configuration, composition, structure, purpose, value, and meaning in man-made things and systems” (Archer, 1981). Therefore, Design Research opens up new ways of thinking about, knowing and doing design (Simonsen et al., 2012). Among the aims of the Design Research Society is to recognize “design as a creative act common to many disciplines [...] to promote the study of and research into the process of designing in all its many fields [...] advancing the theory and practice of design” (Aims of the Design Research Society, 1980).

Nigel Cross, renown design researcher and educator, questions Simon’s concept of “Science of Design”, which aims to improve the understanding of design through scientific methods – as opposed to that of “Design Science”, a term first used by Buckminster Fuller, which is an attempt to extract knowledge from the natural world, with the aim to use it as design input or inspiration (Margolin, 2002). Several researchers agree that Design Research may be distinguished in Research “into” Design, Research “by” Design and Research “for” Design (Cross, 2006; Frayling, 1994; Friedman, 2008). Research into Design is mainly a bibliographical approach, it mainly is the study of a design, building or object that is already finished. Research by Design might relate to material research, development work

or action research, and Research for Design means that the end product is an artefact, in the sense that *“the thinking is embodied in the artefact”* (Frayling, 1994).

Based on Frayling's work, Friedman raises the problematic on Design Research, highlighting *“the failure to engage in grounded theory and developing theory out of practice”* (Friedman, 2008). In his paper he aims to disambiguate the practice-based research as a form of theory construction. He criticizes Frayling's definition of Research by Design as unclear and attempts to cast more light on the subject at hand. Tacit knowledge is obviously important in design disciplines, however *“tacit knowledge and reflective practice are not the basis of research and theorizing”*, a framework of explicit knowledge is required (Friedman, 2008). He questions the misconception that practice qualifies as a research method and explains that *“all knowledge, science and practice rely on rich cycles of knowledge management moving from tacit knowledge to explicit and back again”* (Friedman, 2008). Establishing this constant feedback loop from tacit to explicit knowledge and back is also a central concept in the work presented here, both as part of our research methodology, as well as a workflow during the two seminars at Graz University of Technology.

RESEARCH BY MAKING

Simonsen describes Design Research as a process of knowing, he characterizes designing as *“knowing through making or doing”* (Simonsen et al., 2012). Our approach seeks to extend the paradigm of Research by Design introducing a possible methodological framework and teaching approach of Research by Making. In contemporary architecture education digital-physical experiments play a central role. Research by Making integrates materiality and physical properties in combination with computational methods and digital fabrication. The models resulting from material experimentation may be unpredictable, as they highly depend on material behaviour. However, the tacit knowledge obtained by the students is a foundation for what Donald Schön defines as the designer's *“reflection-in-action”*.

Donald Schön, professor of education and planning at MIT, describes the difference between *“knowing-in-action”* and *“reflection-in-action”*:

Knowing-in-action is *“...the repertoire of routinized responses that skilful practitioners bring to their practice”*, gained through training or experience (Schön, 1985). *“It can be seen as consisting of strategies of action understanding of phenomena, ways of framing the problematic situations encountered in day-to-day experience...It is a dynamic knowing process, rather than a static body of knowledge, in the sense that it takes the form of continuing detection and correction of error, on-line fine-tuning, all within the framework of a relatively unchanging system of understanding.”* (Schön, 1985).

He expounds that if we operate outside our normal routines, outcomes are not as expected - surprises, uncertainty, or non-understanding occur. Therefore, we need to *“reflect”* on our actions, on the spot, so we can still have an impact on the outcome. *“Our spontaneous responses to the phenomena of everyday life do not always work. Sometimes our spontaneous knowing-in-action yields unexpected outcomes and we react to the surprise by a kind of thinking what we are doing while we are doing it, a process I call reflection-in-action.”* The reflection *“... has a critical function, questioning and challenging the assumptional basis of action, and a restructuring function, reshaping strategies, understanding of phenomena, and ways of framing problems.”* (Schön, 1985).

During the seminars presented in this paper, the students engaged in a hands-on approach,

where their choices and “spontaneous responses” highly depended on the material at hand. An elastic material would form different geometric configurations if stretched in a certain way, whereas a manually thermoformed plastic sheet would remain malleable for a specified amount of time, changing its behaviour and subsequently the force needed to form it.

Schön's reflection process offers a huge potential for architects to envision new ideas, solutions and theories:

“Depending on the context and the practitioner, such reflection-in-action may take the form of on-the-spot problem-solving, theory-building, or re-appreciation of the situation. When the problem at hand proves resistant to readily accessible solutions, the practitioner may rethink the approach he has been taking and invent new strategies of action. When a practitioner encounters a situation that falls outside his usual range of descriptive categories, he may surface and criticize his initial understanding and proceed to construct a new, situationspecific theory of the phenomenon.” [Schön, 1985].

Schön's conceptual framework is linked with the philosophical writings of Gilbert Ryle [Ryle and Dennett, 2000], that distinguish between “knowing how” and “knowing that”, which is of particular importance for architecture, as we very often engage in hands-on activities, both in academia and in praxis.

While traditional education starts out from a deep study of the theory that subsequently evolves into generating design praxis, the approach of Research by Making departs from the constructionism point of view that praxis should pave the way to theory. The practical experiments help students to construct the questions that will later be answered by the theory. It is not a linear process; it could better be described as a feedback loop where experiential learning is combined with theory and practice in several iterations. As Ranulph Glanville remarks, one difference between practice and theory is that “theory is created by an observer standing outside the system to describe it, while practice necessarily involves the observer acting within the system” [Rodgers and Yee, 2014]. This is directly linked to the beliefs of Michael Polanyi about “tacit knowledge”, saying that there is a different type of knowledge that cannot be put into words, the experiential knowledge usually related to creative disciplines, associated with the actual praxis. An example of this is the knowledge transfer from a Master artist to the disciple. Polanyi proclaims in his book *The Tacit Dimension* that “we can know more than we can tell” [Polanyi, 1966]. Cash and Culley highlight the role of Experimental Studies in Design Research, as this approach supports both theory building and theory testing [Cash and Culley in Rodgers and Yee, 2014].

Research by Making relates to “constructive design research” introduced in the book *Design Research through practice*, where the authors define this as “design research in which construction - be it product, system, space, or media - takes center place and becomes the key means in constructing knowledge” [Koskinen et al., 2011]. The above definition usually involves a prototype, and in the case of the presented projects, the prototypes are a central part of the design process. It is understood that “without this culture of doing, many things of interest to designers would go unnoticed” [Koskinen et al., 2011].

In this realm, the case studies presented in this paper aim to showcase a hands-on educational approach where students learn by doing, implementing both analogue and digital media for the exploration of architectural form.

LEARNING BY DOING

The following chapters describe two design courses, taught as seminar-series at Graz University of Technology, where educational methods of Learning by Doing are implemented. The two seminars “Analogue and Digital Form-Finding” and “Digital Fabrication” aim to showcase the Research by Making methodology and the educational benefits of this pedagogical approach.

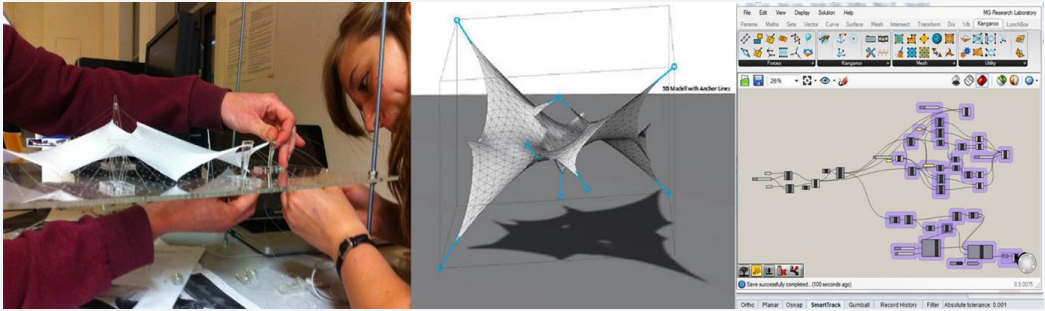
Seminar 1: Flexible Matter: An Analogue and Digital Approach to Form-Finding

The first course introduces real-time shape exploration employing analogue and digital form-finding. The students embark on a hands-on experimentation with tensile structures resulting in design proposals for lightweight structures. The experiments involve physical form-finding, following the tradition of Frei Otto, as well as computational form-finding, simulating tensile and bending behaviour with the use of dynamic relaxation of spring-particle systems (Kangaroo plugin for Rhino). By establishing feedback between digital media and physical prototypes, the creative process is informed by the material characteristics and structural properties. The aim is to utilize the parametric model not merely as a representational tool, but as a morphogenetic tool, that embeds the physical behaviour and interaction among tension-active elements, giving rise to structurally optimized forms.

The Flexible Matter workshop at Graz University of Technology started with a set of analogue experiments on a measured plexiglass frame where elastic textile (with elasticity in both directions) was tensioned. The first set of experiments involved the form-finding of typical tensile structure primitives, such as the Hypar, Conic and Barrel Vault, together with possible combinations of the above. Thus, already from the initial design stages, the elasticity and material characteristics led to a vocabulary of possible formations within the broader category of tensile structures. This set of experiments also studied the repercussion of a 2D cutting pattern on the 3D form, understanding the translation of forces into geometry, the continuity and discontinuity of force transfer as a design gesture. A tensioned membrane, just as the soap films of Otto, tries to minimize its material (energy) to span between the given borders. The pressure is the same on both sides of the soap film, so the material system settles in a configuration with mean curvature as close to zero as possible. Each modification in the location of an anchor point or tensile force will have a direct repercussion on the form, so that all forces acting upon the model are in equilibrium. Thus, design decisions are taken by the material itself and the forces acting upon it.

A physics engine, such as Kangaroo, acts as a design decision support system; it assists architects to increase their intuitive understanding of the structural behaviour of geometrically complex forms. *“The environment educates the user as to the effects of forces on the form of structures and provides an interactive form-finding”* (Kilian and Ochsendorf, 2005). While traditional architecture and engineering aims at the structural optimization of an existing form, a dynamic form-finding system can lead to a real-time discovery of structural form encouraging the morphogenesis of optimized structures.

Considering a pedagogical approach of Learning by Doing, the students investigated known architectural case studies by making models, understanding the morphogenetic principles that govern the construction. This was not an exercise about copying the external form, it was rather an exercise about understanding the principles that generate the form. A hands-on approach encourages tacit knowledge, which combined with the theoretical background, leads to more informed decisions. As Koskinen explains, a design process *“may start from theories, methods, and fieldwork findings, and just as often it*



▲ Figure 1 Students experimenting with analogue and digital form-finding of membranes.

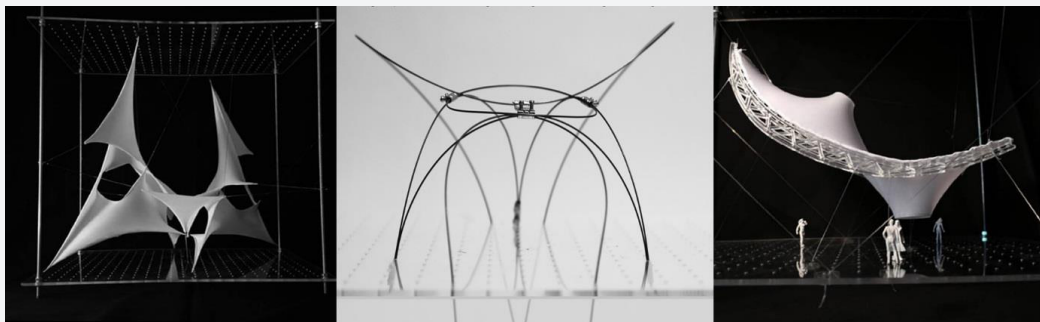
begins with playing with materials, technology, and design precedents” [Koskinen et al., 2011]. With this attitude in mind, the workshop’s experimentation departed from the study of built examples to further evolve into original design ideas. The built examples that were used as case studies were drawn from various different periods of architectural history, thus ranging from the Institute of Lightweight Structures (ILEK) to the Paradise Pavilion by Chris Bosse.

Extracting the underlying generative logic of the analogue experiments and understanding the forces in play is the first step towards building a digital setup that simulates the physical behaviour. For solving similar problems, Dynamic Relaxation of spring-particle systems has been used for over three decades in the engineering world [Day, 1965]. However, the recent integration of visual algorithms such as Kangaroo Physics in Grasshopper [Piker, 2013] has resulted in a very user-friendly and intuitive tool in the hands of architects.

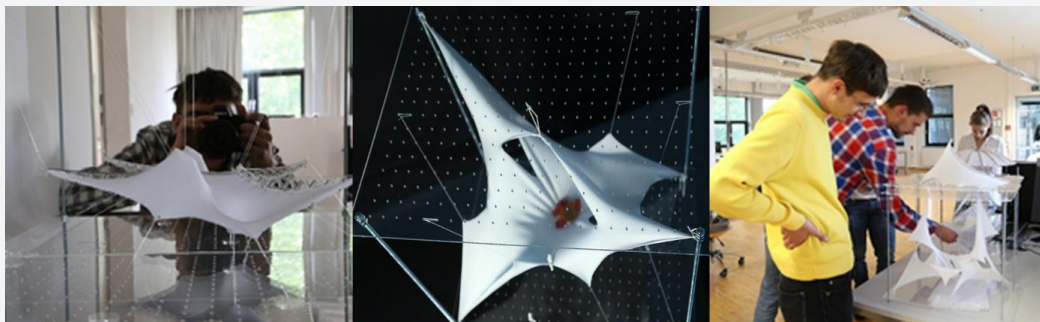
In an attempt to mimic the physical behaviour of a material system, we translate physical properties into mathematical equations that generate the geometry in the computational environment. Thus, an elastic textile can be represented by a spring-particle system, translating mesh vertices to particles and mesh edges to springs, in other words a system of points and lines. The Kangaroo physics engine computes forces, velocity and lengths of springs that behave according to *Hooke’s Law*. Having obtained an understanding of the forces acting upon the models, the students were able to build their own Grasshopper definitions, compare the results to the physical models and rectify any of the two. In several cases, the form-finding experiments revealed some unpredictable results that emerged from the self-organizational capacity of the system to regulate and distribute forces to reach equilibrium. As Piker explains *“one great advantage of physically based methods is that we have a natural feel for them, and this intuitive quality lends itself well to the design process [...] through the application of real-world physics we can make computational tools that really work with us to design in a way that is both creative and practical”* [Piker, 2013].

Students had the chance to get their “hands dirty” and acquire experiential knowledge about tensile structures. The process involved less thinking and more making, the students faced problems and developed strategies to solve them. Aware of the potential of the material system at hand in a conscious and intuitive level, they were liberated from the restrictions of the tools and motivated to pursue their design ideas.

During the development of the projects, students implemented analogue and digital media in parallel. There was a conceptual feedback across media, which aided students to take



▲ Figure 2 Models of tensile structures and elastically bending elements developed during the workshops.



▲ Figure 3 Models of tensile structures developed during the workshops.

informed design decisions. It is important to clarify that we are not looking at analogue-digital processes as two competing strategies, but as complementary tools that provide different type of input yet interrelated with each other. Analogue tools proved more efficient with handling qualitative characteristics of the design, transmitting the atmosphere of the architecture, understanding empirically the forces acting upon the structure, dealing with issues of assembly, and detailing (Symeonidou, 2015). In contrast, digital tools can handle huge amounts of data, making them appropriate for handling quantitative characteristics of the design. They allow quick changes but they require certain experience with real-world physical forces, so that the user can calibrate the values for drag, spring force and edge conditions.

In particular, the use of prototypes in early design stages conveys a lot of embedded design information. However, as Stappers explains, “the value of prototypes as carriers of knowledge can be implicit or hidden. They embody solutions, but the problems they solve may not be recognized” (Stappers, 2007). Therefore, they represent great design tools for an exploratory phase of design ideation.

The aim of the workshop was to intrinsically involve analogue and digital design processes, not as separate routines, but as an integrated design approach, where the two media counter-inform each other from the very beginning of the design lifecycle.

Understanding the association between geometry and material behaviour, the elastic properties of membranes or computational spring meshes and the obtained form, leads to a “synergetic approach to design integrating form, structure, material and environment” (Oxman and Rosenberg, 2007).

The presented projects show an overview of the techniques and methodologies investigated during the Flexible Matter workshop that took place at Graz University of Technology. It addresses issues of design research through praxis, and design processes that encourage creative design thinking towards an integral approach in architecture, which integrates material behaviour, functionality, material economy, aesthetics and optimized structural performance.

Seminar 2: Manual and Robotic Forming: An Open Negotiation between Human, Machine and Material

In the second course, manual production of prototypes is combined with digital fabrication, working in the interdisciplinary field between design, craft and robotics. It investigates open design experiments, where form arises in a dynamic interplay between the operator/designer, the material and the robot. In an experimental set-up, students explore possible shapes and design outcomes by thermoforming flat sheets into 3-dimensional objects - manually or robotically. The course is project-based, allowing students to learn by experiencing and making their own discoveries, giving them a starting point and guidelines, combined with skill building sessions.

Architectural education is traditionally often based on “Making” - this contemporary approach combines manual, digital, and material aspects. As the role of the architect changes in the design-to-build chain with the increasing use of digital fabrication, this paradigm shift has to be addressed in education. Our relation to materiality changes, offering possibilities to have bigger control over the fabrication phase and integrating these aspects in the early design-phase. The course examines the potential that arises, when production tools - manual or machinic - are used as key part of the design process, which a special benefit of linking these two ways of “Making” by digital tools, i.e. a motion capture system.

Within the realm of digital fabrication, robotic technology plays a special role, because of its leeway for customization. Gramazio and Kohler, pioneers in the use of robots in architecture at ETH Zurich, write about it: A robot “... has not been optimized for one single task but is suitable for a wide spectrum of applications. Rather than being forced to operate within the predefined parameters of a specialized machine, we are able to design the actual “manual skills” of the generic robot ourselves.” (Gramazio and Kohler 2008). The approach employed in the presented seminar uses this special advantage of a robot: to work with customized end-effectors. Thus, the same operation that is done manually can be replicated by a robot. By using the same experimental set-up for hand and robotic forming, both processes are relatable and comparable.

At the beginning of the seminar, each student (our student group) is equipped with a set of materials and tools: a number of plastic panels, a frame to hold the panel, a set of geometry tools to form the surface (“deformer”), and a heat gun. The panels are shaped by manual and subsequently by robotic movement, in conjunction with a local, form-giving counterpart. By complex movement operations like push, tilt, twist, and shear, planar materials are transformed into customized elements. The final geometry is not pre-defined (in the digital realm) before materialization - it emerges during the actual production process. A result is anticipated, but the expectations are not always fulfilled: surprises and discoveries happen, as well as accidents.



▲ Figure 4 Students exploring hand forming and motion tracking.



▲ Figure 5 Students exploring hand forming and motion tracking.

Alternating with the “Making”, the participants receive lectures and tutorials, about manual techniques and digital tools. Furthermore, they are introduced to the fabrication machines employed in the course - a laser cutter and a 6-axis industrial robotic arm - as well as to the motion capture system installed in the school lab. The actual contact with the equipment is vital for the skill building and acquiring of tacit knowledge previously discussed. Experimenting with a range of new tools, the students develop curiosity and learn by doing, getting directly involved in the design process by making.

By means of hand-forming of the panels, the participants are introduced to the material and forming behaviour of plastics (acrylic glass, polystyrene, PET) when exposed to different temperatures. Thereby, possible shapes and design outcomes are explored. These hands-on experiments are crucial for building up a design intuition, which further informs the digital process. As Bechthold and King describe it, “...physical and digital experiments produce many ideas in rapid sequence. Rough prototypes, even those produced manually, provide early feedback on opportunities, but also help failures to emerge quickly. The evaluation criteria derived through the analysis are used to filter out ideas for further development...” (Bechthold and King 2014). The students benefit immensely by starting directly with a hands-on-approach, gaining knowledge about forming, timing and distance of heating. After producing their first test models, students are able to evaluate and select the most successful experiments and continue with a clearer design intent. One of the main research-achievements in this seminar is the understanding of the relation between manual and robotic forming. This is accomplished by capturing the hand-forming process with a motion tracking system. Using camera-based technology, the most successful hand-forming outcomes are recorded. The students “choreograph” scenarios, which they develop in the manual forming test. The movement and speed of the crafted processes are recorded and translated to robotic operations.

Different ways of translating the tracking data to the robot are used: from direct translation, over picking one pattern and replicating it, to altering and optimizing the



▲ Figure 6 Prototypes developed by the students during the seminar.

manual process. The students make use of several different software packages and plugins, including Rhinoceros, Grasshopper and HAL, a Grasshopper plugin for industrial robots programming. This enables them to programme the robot easily, and adjust processes simply by moving sliders.

The outcomes of the experimental case-studies offer a great insight on the relation between craft and machine, as well as on their respective advantages and disadvantages. The biggest advantage of hand-forming is the quick start and the freedom of operations that can be performed by hand. Manual forming may induce some imprecision in the heating area and the forming movement by hand. This is seen as an exploratory phase that can be further refined with the use of digital media. Through this iterative workflow, students exploit the advantages of digital and robotic technology: to adjust processes parametrically, to precisely replicate successful prototypes, or to create parametric variations of a module. In this approach, intuition, manual skills, material properties and machine processes are linked in a dynamic interplay. Reflection is taken on the produced prototypes, drawing conclusions on the design potential for similar materials and design processes.

CONCLUSIONS

In the studio-based courses described above, form is the result of manual or robotic gestures of stretching, bending, heat forming. De Landa would describe such a process as an “analogue search algorithm”. We refer to physical experiments as “analogue computation” because the material “computes” its form - it self-organizes for a given set of boundaries, forces, temperature or other constraints. Having understood the modus operandi of Research by Design, we combine new techniques and methodologies, taking a step further into Research by Making as a method of architectural inquiry. One of its main benefits is to foster intuition, knowledge and “*reflection-in-action*”. Linking digital and manual fabrication allows for building up new sensibilities by experiencing and making. This digitally extended Design by Making workflow fosters a new way of thinking about architectural design and practice, based on exploration of materiality. Other than in typical prototyping, the result is not simulated before production, providing an open field for experimentation. If properly employed, this methodology can unlock creativity and the discovery of new aesthetics and formal languages. Engaging research-based education as we understand it, students are able to gain skills in cutting-edge topics of the architectural discourse. In a pedagogical point of view, they are encouraged to be curious, willing to take risks, move out of their comfort zone and operate in a field of uncertainty. A Research by Making approach challenges students to expand their skills and design-thinking methodologies. They acquire new knowledge, both tacit and explicit, are able to construct their own theory and test the concepts they previously learnt in architecture school by actually building small-scale prototypes.

The role of model making in architectural education is well established in the academic curriculum, and digital media have brought a new dimension to traditional model making [Stavric et al., 2013]. Brett Steele alludes to the common belief that “*architecture is only ever learned by getting your hands dirty*” (Self and Walker, 2010). He explains that this is done through the construction of physical prototypes, 1:1 models, whose “*working difficulties and eventual results offer the designers vital insight and understanding into how they take a next tentative step forward*”. The technological developments in CAD/CAM may have achieved a seamless transfer of information from designing to making, a file-to-factory continuum from the computer screen to the CNC machine. However, as we observed, the creative process itself is not so easy to trace, very often thoughts are fragmented, discontinuous, yet creative, jumping from one idea to another, taking one informed decision, followed by a random or controversial design gesture. In the same fashion, a designer implements different media during the design process.

In the framework of the student seminars presented in this paper, the challenge was to adopt an integral approach to design, informed by material properties. The aim was to address computation in its multiplicity negotiating material, structure, design and function. This scheme enabled us to go beyond the established morphological vocabulary into more experimental and non-standard geometries, as well as to employ and assess a novel attitude towards design teaching, introducing cutting-edge technology through experiential learning.

ACKNOWLEDGEMENTS

This research is supported by the Institute of Architecture and Media, the Institute of Structural Design, and the ABB Roboter-Labor at Graz University of Technology. Special thanks for the support to Urs Hirschberg, Milena Stavric, Paul Frick, Ludwig Grimm, Jacob Wegerer, Felix Amtsberg and Richard Dank, as well as to all participating students in the seminars: A. Jäger, A. Moteva, C. Primschitz, D.Ferreira Arias, F. Scheucher, G. Murrer, H. Yan, I. Lichtenegger, M. Kossuth, L. A. Zitterer, M. Monsberger, S. Neumann, R. Patricio, P. Wayd; T. Hopp, M.B. Mateev, M. Prosekar, J. Petersen, R. Starmutz, W. Thiemann; M. Gratzner, M. P. Handley, G. Hoppe, J. Jauk, S. Milenkovic, R. Olason, A. Paul, B. Schmid, C. Thambauer; J. Aigner, L. Albrecht, P. Flachhuber, I. Fuchs, E. Huta, E. M. Kern, E. Kertusha, M. Klaus, P. Knoll, J. Lebitsch, V. Moser, G. Pavic, B. Raskaj, T. S. Roser, M. Sar, P. Schitter, B. Sipka, A. Sorger, P. Vinicki, K. Wagner, L. Wokatsch.

REFERENCES

- Aims of the Design Research Society [WWW Document], <http://www.designresearchsociety.org/joomla/about/aims.html> [accessed 1.18.16].
- Anderson, J., 2010. Basics Architecture 03: Architectural Design. AVA Publishing.
- Archer, B., 1981. A view of the nature of design research. IPC Sci. Technol. Press, Design Science Method 30–47.
- Bechthold, M & King, M 2013, ‘Design Robotics - Towards strategic design experiments’ in Rob|Arch 2012, eds S Brell-Çokcan & J. Braumann, Springer-Verlag, Wien, pp. 118-129.
- Biggs, M., 2002. The role of the artefact in art and design research. Int. J. Des. Sci. Technol. 10, 19–24.
- Borgdorff, H., 2006. The debate on research in the arts. Kunsthøgskolen i Bergen.
- Buchanan, R., 2001. Design Research and the New Learning. Des. Issues 17, 3–23. doi:10.1162/07479360152681056
- Cross, N., 2006. Designerly ways of knowing. Springer, London.
- Day, A.S., 1965. An introduction to dynamic relaxation. The Engineer 219, 218–221.
- De Landa, M 2012, Manuel DeLanda keynote lecture, lecture notes from ACADIA conference, San Francisco, on 24. October 2012. Available from: <<http://frmlab.com/2012/10/24/live-keynote-manuel-de-landa-acadia-day-4>> [18 January 2016].

- Frayling, C., 1994. Research in Art and Design, in: Royal College of Art Research Papers, Vol 1, No 1. London.
- Friedman, K., 2008. Research into, by and for design. *J. Vis. Art Pract.* 7, 153–160.
- Gramazio, F & Kohler, M 2008, *Digital Materiality in Architecture*, Lars Müller Publishers, Baden.
- Groat, L., Wang, D., 2001. *Architectural Research Methods*, 1 edition. ed. Wiley, New York.
- Kilian, A., Ochsendorf, J., 2005. Particle-spring systems for structural form finding. *J.-Int. Assoc. Shell Spat. Struct.* 148, 77.
- Koskinen, I., Zimmerman, J., Binder, T., Redstrom, J., Wensveen, S., 2011. *Design Research Through Practice: From the Lab, Field, and Showroom*, 1 edition. ed. Morgan Kaufmann, Waltham, MA.
- Margolin, V., 2002. *The Politics of the Artificial: Essays on Design and Design Studies*. University of Chicago Press.
- Matthews, B., Buur, J., 2009. *Teaching design research in the studio*. Nordes.
- Menges, A 2012, *Material Computation*, AD, John Wiley&Sons Ltd., London.
- Oxman, N., Rosenberg, J.L., 2007. Material-based design computation: An Inquiry into digital simulation of physical material properties as design generators. *Int. J. Archit. Comput.* 5, 26–44.
- Piker, D., 2013. Kangaroo: Form Finding with Computational Physics. *Archit. Des.* 83, 136–137. doi:10.1002/ad.1569
- Polanyi, M., 1966. *The Tacit Dimension*. University Of Chicago Press, Chicago.
- Rodgers, P., Yee, J., 2014. *The Routledge Companion to Design Research*. Routledge.
- Ryle, G., Dennett, D.C., 2000. *The Concept of Mind*, 1 edition. ed. University Of Chicago Press, Chicago.
- Schön, D 1985, *The Design Studio: An Exploration of Its Traditions and Potentials*, RIBA Publications, London.
- Self, M., Walker, C., 2010. *Making Pavilions*. Architectural Association Publications, London.
- Simon, H., 1996. *The Sciences of the Artificial*, 3rd edition. ed. The MIT Press, Cambridge, Mass.
- Simonsen, J., Bærenholdt, J.O., Büscher, M., Scheuer, J.D. (Eds.), 2012. *Design Research: Synergies from Interdisciplinary Perspectives*. Routledge, London.
- Stappers, P.J., 2007. Doing design as a part of doing research, in: Michel, R. (Ed.), *Design Research Now*. Birkhäuser Architecture, Boston, MA.
- Stavric, M., Sidanin, P., Tepavcevic, B., 2013. *Architectural Scale Models in the Digital Age: Design, Representation and Manufacturing*. AMBRA, Wien.
- Symeonidou, I., 2015, 'Flexible Matter - A Real-Time Shape Exploration Employing Analogue and Digital Form-Finding of Tensile Structures' in *Real Time: proceedings of the 33rd eCAADe Conference - Volume 2*, eds B Martens, G Wurzer, T Grasl, WE Lorenz & R Schaffranek, Vienna University of Technology, Vienna, pp. 135-142.
- Weissenböck, R 2014, 'D-FORM: Exploring the Combination of Laser Cutting and Robotic Thermoforming as a Technique for Architectural Envelopes' in *Robotic Fabrication in Architecture, Art and Design 2014*, eds. W McGee & M Ponce de Leon, Springer International Publishing, pp. 249-260.
- Weissenböck, R 2015, 'Robotic Design-Fabrication' in *Real Time: proceedings of the 33rd eCAADe Conference - Volume 2*, eds B Martens, G Wurzer, T Grasl, WE Lorenz & R Schaffranek, Vienna University of Technology, Vienna, pp. 309-318.

Design methods: deep agencies for spatial production

Perry Kulper

Taubman College of Architecture and Urban Planning, University of Michigan, USA

"Methodological straight-jackets can only suppress the emergence of new ideas. Theoretical imperialism is stifling... many people repeat these principles most piously, even turning them into some kind of orthodoxy; very few actually come up with new ideas by putting them into practice." Introduction to Detachément (by Michel Serres), René Girard

Design Methods: Deep Agencies for Spatial Production argues for increased exposure, critical positioning, and acupuncture-like use of design method in the design studio. Three primary points regarding the agency of design methods are leveraged and positioned: (i) the virtues of increased design versatility; (ii) the production of innovative form; and (iii) the construction of disciplinary knowledge. Fourteen design methods are identified, select design methods are drawn out and thickened (i.e., articulating the definition, etymology, preferences, author relations, (in)directness to architecture, template for operations, and case studies) and four specific design method frameworks are supplemented by design examples.

INTRODUCTION

Increasingly, a primary challenge facing the architecture design studio is the lack of understanding that a discipline for design must be established - specifically in relation to effectively implementing design methods when designing architecture. Operating in the margins of current architectural debates, the critical location of design methods and their respective affordances has been relegated to the blind spots of spatial production - suppressed by more dominant pedagogical agendas. As educators, we must recognize and address this crucial aspect of spatial education if architecture is to remain vital in augmenting the cultural imagination.

Given the changing nature of political, geographical, and cultural spacescapes, these thoughts suggest that we frame, position, and embrace multiple means for making work - augmenting ossified and limited understandings of methods for design. Flows of capital, global interconnectedness, and technological advances are challenging static, and perhaps outmoded notions of architecture. This suggests that we raise our individual and collective awareness of diverse design methods to negotiate the surge of changes: increasing our design dexterity and versatility to optimize the capacities of spatial realms; to advance innovative form - when appropriate; and to contribute to the continuous development and transformation of disciplinary knowledge.

FRAMING

For the sake of making a point, I suggest, exaggeratedly, that many architects - including this one, are spatially myopic. This myopia mutes architecture's real agency, imaginative potential and cultural durability. Causally linked to a reliance on categorical and typological fixity, totalizing approaches and homogeneous project ideas, our individual and collective spatial imaginations are fatigued, further draining the generative cultural and practiced capacities of architecture. Post-Enlightenment byproducts, including systematization, a reliance on empirical knowledge, architectural autonomy, and pragmatic domination, contribute to this atrophied sense of spatial wonderment.

Recently, architecture and schools of architecture have been driven by problem-solving approaches; the ever-present weight of the program - the default and uncritical ghosts of functionalism lurking; formal techniques; and the here today, gone tomorrow fashion regime. Articulated through myriad vocabularies of modernism, late modernism, high- tech, deconstruction, folding, field thinking, and more recently, topology, affect, technique, contemporary processes and all things "post," these developments have helped shape recent discourses in architecture, particularly in education. While many contributions have been made, these histories seem exclusive, frequently leading to autonomous and non-participatory architecture. A projective positioning of design methods would augment these spatial and discursive developments, offering footnotes to these more dominant histories by leveraging another scope for architecture.

Critical method involvement might shed light on much that remains unquestioned and accepted by default - valuing speculation, authentic spatial production, and the expansion of architectural knowledge by grounding itself in the cultural, ethical, material, and methodological aspects of spatial production. To accomplish this requires contextualizing discussions and developing a diverse range of skills, not the least of which is engaging with multiple value systems and aesthetic possibilities. Design method expansion can play an important role on this front.

14 DESIGN METHODS, OR 11 DESIGN METHODS AND 3 TECHNIQUES: WORKING NOTES

I've identified 14 design methods - they aren't 'correct' or the only ones. They are, however, diverse in make-up, highly varied in operating potential and capacity. Their use facilitates radically different outcomes. They can be combined, translated, tailored, and even invented, tuned to the particular questions at hand.

With respect to design, some methods are direct, others more indirect, some requiring modes of translation or affiliations with other design methods. On the ground they are linked with various kinds of representation techniques - 2D, 2½D, 3D, and other Ds. To avoid confusion, these thoughts focus on the design methods themselves, rather than on the techniques of representation that might be linked to particular methods. The fourteen are organized alphabetically with a couple of points made about each method. To establish some range in method diversity, four of them -syntactical means, gestural translation, appropriation, and analogic means are drawn out and supplemented with work samples.

1. "Analogic" means for design works through likenesses - "this form is like that", "this behaves like that" and so on.
2. "Appropriation" as a means to work is to find or to take for one's own use or to take (im) properly, as with(out) permission.
3. "Automatism" defies logic and rationality, attempting to remove obstacles to the creative imagination - André Breton defined surrealism, for example, as "pure psychic

automatism.”

4. A “content to form” means of working begins without material or formal destinations - the method enables a designer to work from issues, topics or ideas toward producing spatial conditions.
5. “Diagramming” (one of the three methods identified here that might more accurately be a technique - indexical and notational means are included in that possibility) sets a fabric of information into play - relational assemblies visualized through abstract visual means.
6. The “form to programme” method (attributed to architect and educator Kevin Rhowbotham) of designing challenges “form follows function” spatial agendas. In this design method, formal and material possibilities precede program logic, opening the expansive possibilities for both what form and programs might be.
7. “Gestural translation/interpretation” suggests a two-part sequence - one of gestural generation and one of translation or interpretation. This method frequently occludes or delays meaning or content in lieu of another way to generate form.
8. “Indexical means” for working is one of the least direct relative to architectural production. This method is often detached from form and temporal circumstances, instead pointing to other things through developing indexes arranged or deployed, indirectly toward spatiality.
9. If “analogic” means trades on likenesses, then “metaphoric” means trades on differences that are brought together where a word, phrase or thing that normally designates one thing is used to designate another, making an implicit comparison.
10. The “narrative” design method uses the familiarity of storytelling, enabling a designer to set up a narrative construction, following it as a guide for designing. Notably, this differs from narrative as sought after meaning or communication in a piece of work.
11. “Notational” means for working negotiates parts of a schema, enabling something to be enacted over and through time—a kind of coded matrix of time and space potential.
12. “Parametric modeling” is fairly common these days. Here, the author selects any range of variables, commonly within a familial range, and subsequently develops representational abstractions of those chosen parameters, frequently qualified by software protocols.
13. And then there’s “plagiarism”—the copying and taking someone else’s work and claiming it as your own. Without condoning it, this form of working is legitimate, but has many ethical questions attached to its operating agendas.
14. Finally, “syntactical” means for working enables the development of architecture through iterative operations or rules, normally formal and usually devoid of political, social or experiential grounding.

DESIGN METHOD CONSIDERATIONS

When engaging design, the terms of design methods are seldom explicit, frequently leaving a designer isolated and lacking a contextual and operational background from which to design. These circumstances render students and professionals underprepared to optimize the opportunities that significant shifts in cultural, technological, and temporal conditions afford. If key considerations are taken seriously, the potential for design method involvement toward increased design versatility, innovative spatial make up, constructing disciplinary knowledge, interdisciplinary connections, and a real politics of communication are extraordinary.

It is critical to lay bare the cultural and architectural context in which methods and their attendant values were developed, worked with, and transformed. Methods have distinct characteristics - from operating protocols; to yielding form and material possibilities, or

not; and to the kinds of things that can be worked on in a project. Identifying key areas for framing methods is essential for optimizing what methods afford and include: the etymology, or origin of a method; its operating preferences, biases, and limitations; the roles of the author(s); the (in)directness to get to form when designing architecture; its extended referential structure; developing a template for operations - a kind of road map - for implementing a given method; case studies; and means for assessing the methods' use.

Some methods are linked to particular cultural movements and developments - "automatism" to Surrealism or "parametric modeling" to developments in mathematics and the sciences. Others evolve in more informal ways, accumulating density through practices over time - "appropriation" comes to mind. Still others are more approximately formulated, loosely tied to cultural practices from art making, to writing literature, and to the animate potential of our bodies - "gestural translation." Regardless of the method's origin, it is important to understand them as grounded in the history of ideas, in the world of cultural production, and in the spatial settings of our lives, both real and speculative. It is crucial to qualify them relationally - rather than as hermetic and autonomous slaves at our beckoning call.

METHOD PROFILES

Locating design methods in a larger context is paramount to their effective use - knowing that some are linked to spatial practices, others to art, and some to literature and the sciences. Articulating a method's etymology, culturally and architecturally, locates it in the larger history of ideas, establishing dialogic continuity. Identifying the progenitors, offspring, and known trajectories of a design method is equally important.

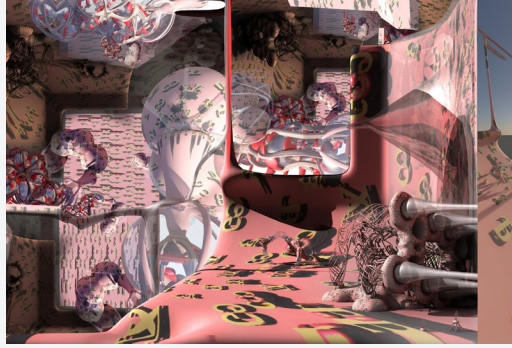
When considering the preferences of a method, it is important to specify what it does well and what kinds of things it does not allow. A "narrative" means for working (not narrative content), for example, may not allow accidents or chance, whereas "automatism" suppresses rationality and embraces spontaneity and chance through un- or subconscious forms of authoring. Where "automatism" supports the irrational, "parametric modeling" values selecting variables, firing on the logic and curatorial virtues of the author and the biases of software application. Understanding whether a method leads to making form, to meaning, abstraction, informational relations and authorial power is also significant. This understanding contributes to the possibility of a more effective method use over default means for designing.

The roles of the author vary significantly from method to method. Some methods lend themselves to single, multiple, or other kinds of authors. They require different kinds of energy to work - reflective, cyclical, spontaneous, disciplined. Some suggest making judgments as the design process evolves, others don't. In the "content to form" method, for example, assessments might be made regularly, yet when working "automatically" judgment would be avoided. To reflect on authorial roles (even within design methods that attempt to remove the author - self-generating methods, for example) is important in positioning and using various design methods.

Some methods lead to an architectural or spatial result quickly and directly, whereas others are linked to subsequent translations and interpretations. Working through "indexical" means, for example, requires making translations, whereas with "appropriation" or even "analogic" means, a spatial result may be almost immediate. The directness, or indirectness, toward spatial make up has several ramifications, not the least of which relates to the efficacies of decision-making, form, or not, and speeds for working.



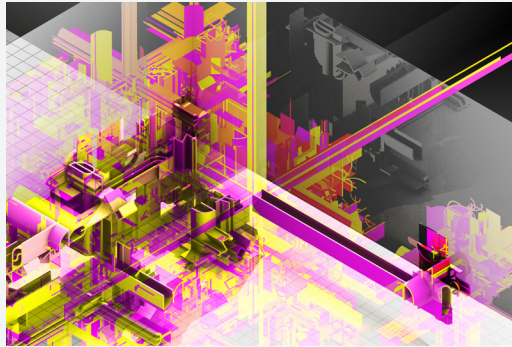
▲ Figure 1a Spatial Syntax



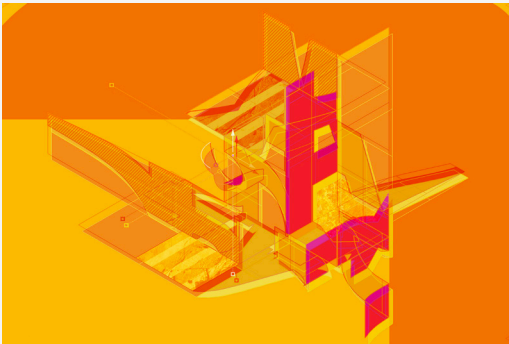
▲ Figure 2a Spatial Syntax



▲ Figure 3a Spatial Syntax



▲ Figure 4a Spatial Syntax



▲ Figure 5a Spatial Syntax



▲ Figure 6a Spatial Syntax

When using design methods it is useful to determine whether one is responsible for extended relations, and if so, what kinds of opportunities might be engaged? When working “syntactically,” for example, the work is likely to be autonomous, or self-contained, whereas “appropriation” is referentially woven. Challenging the autonomy of a method is essential – necessary – if trying to increase the versatility and dexterity of a designer.

It has proven extremely productive to identify the ingredients and choreography of variables needed to work with design methods – developing a kind of template for operating. Seldom do designers work with a single method, and it may be necessary to invent new methods, to combine or hybridize them. In any case, it is useful to understand the operating sequence,

to anticipate when a particular means for working yields to another method, and what kinds of representation techniques are productive and where form and material make up might come into play. Here, developing confidence in deploying any range of methods by making familiar a sequence of operations that are attached to a specific means for working.

4 DESIGN METHODS + WORK SAMPLES

Syntactical Means: Framing

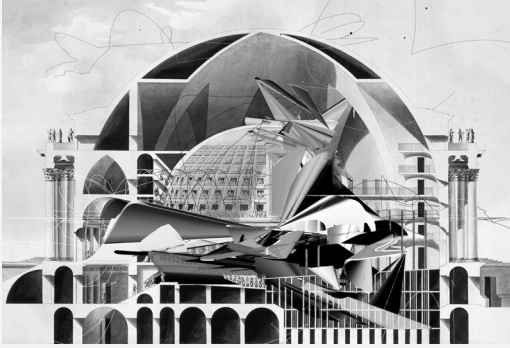
In linguistics, syntax is the study of the rules and principles that govern sentence construction, and in mathematics the term relates to the rules that structure its systems. As a design method it is normally used to develop formal grammars. We might trace its use to the Neo-Classical architect J.N.L. Durand (1760-1834) and his combinatory use of modular units that anticipated industrialization and totalized systems thinking. More recently, Peter Eisenman's early houses are an example of rules systematically pursued through drawing operations, enabling a formal grammar with an occasional material coding.

In (Figures 1a-6a) students in a seminar were asked to develop a set of rules or guidelines to produce spatial formations digitally. They were encouraged to use software such as Rhino or Maya rather than Photoshop or Illustrator. Each student developed systematic instructions - extrude, bisect + code, rotate + loft, re-scale, reverse inflect, for example. The degrees to which the procedural design steps were recognizable in the final formations were left to their discretion. The site for this work was abstract, comprised of 6 1/3 alphabet-like letterforms. The letterforms could be scaled, nested, arrayed, or distributed according to a developed rule set. The letterforms were pink and yellow, they could be opaque or graduated, and they could be 2D, 2½D, or 3D forms, digitally modeled.

Gestural Translation/Interpretation: Framing

Gestures are non-verbal communications in which bodily actions articulate any range of things through the movement of the face, hands, or arms. The word translation originates from Latin, meaning "to carry across" or "to bring across". Our bodies are simultaneously highly evolved and primitive, loaded with potential to articulate spatial or pre-spatial formations. A design method that trades on body potential, gestural translation requires translation from the gestures to the possibility of actual spatial formations. For example, imagine two to three people gesticulating wildly to a favorite Michael Jackson tune or dancing the salsa, capturing those moves on eight axially oriented video cameras, and then downloading and translating the temporally constructed spatiality as an architectural formation - implicating geometry, movement, speeds, and intensity in the formal and material possibilities. Or, how about a spontaneously created red lipstick wall drawing, enacted over different periods of time, with a pheasant feather pinned quickly onto the wall drawing - sequentially translated through forms of digital modeling, implicating position, geometry, and materiality. Parenthetically, the gestures can be forethought, invented on the spot, a series of reactions to other forces, or a combination of all of the above.

So, there are the characteristics of the gesture(s) and the translation. Then, in the work shown here (Figures 1b-6b), there is the aspect of situating the formations, representationally. In this case, the site for the generated spatial formations came from images of drawings by one of three French, Neo-Classical, visionary, and, some would say, revolutionary architects' spatial speculations - Etienne-Louis Boullée (1728-1799), Claude-Nicolas Ledoux (1736-1806), or the slightly lesser known Jacques Lequeu (1757-1825). Their drawn proposals for the 'Cenotaph for Newton', the 'Temple of Equality', the 'Temple of



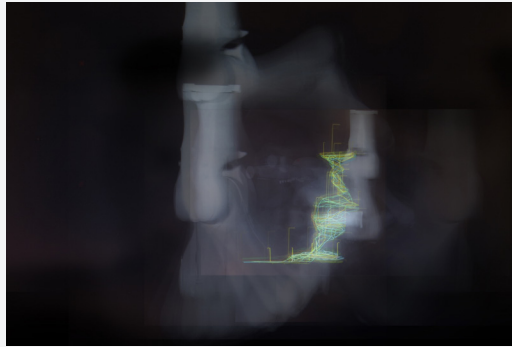
▲ Figure 1b Gestural Translation



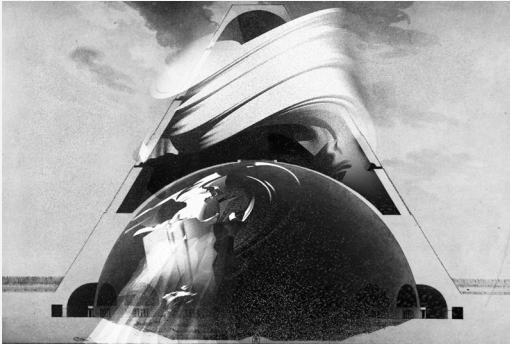
▲ Figure 2b Gestural Translation



▲ Figure 3b Gestural Translation



▲ Figure 4b Gestural Translation



▲ Figure 5b Gestural Translation



▲ Figure 6b Gestural Translation

Death', the Elephant monuments, and so on were fair game. Each student worked with a section from one of these architects, occupied with the relational properties of the section, its representation techniques and any other aspects of the appropriated image in the relation to the gesturally motivated and digitally translated work.

Appropriation: Framing

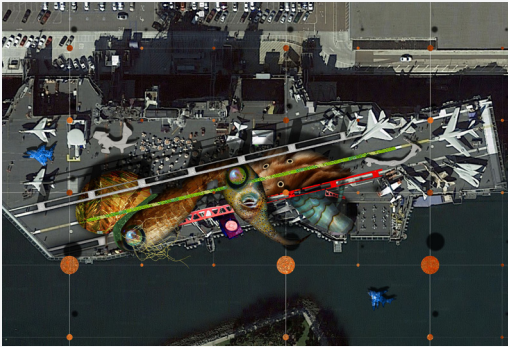
In the arts, appropriation is the use of found or pre-existing objects or images without change or little change to the original material. While established through the development of things such as cabinets of curiosity or *wunderkammer* in the 16th century, appropriation was ushered in as a legitimate form of cultural production by artists such as Pablo



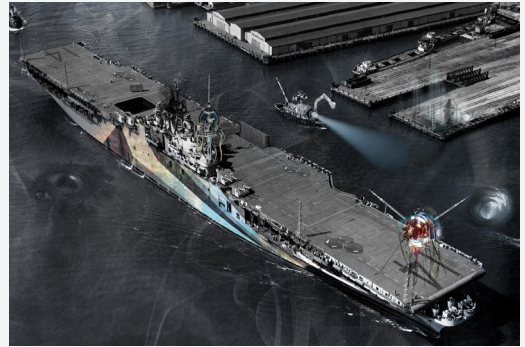
▲ Figure 1c Appropriation, Painted Ceiling



▲ Figure 2c Appropriation, Painted Ceiling



▲ Figure 3c Appropriation, Aircraft Carrier



▲ Figure 4c Appropriation, Aircraft Carrier



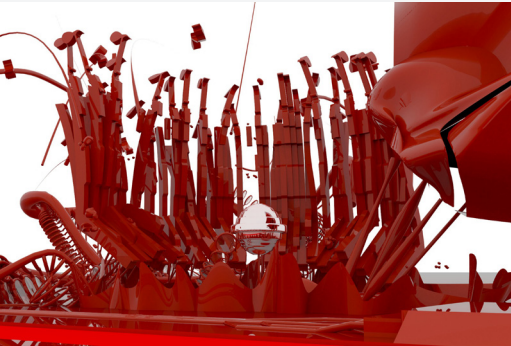
▲ Figure 5c Appropriation, Quarry



▲ Figure 6c Appropriation, Quarry

Picasso and Georges Braque in the early 20th century - and by the Surrealists and Dada artists, most notably Marcel Duchamp, a few years later. Arguably, appropriation became a pervasive, almost symptomatic face of identity for the 20th and 21st centuries. Linked to practices of collage, assemblage, and photomontage, this method allows the artist to produce new work by gathering existing material and combining it with things from another context - bringing together distant realities to produce new forms of cultural production. Anyone can do it; there is no special training or context for using the method required.

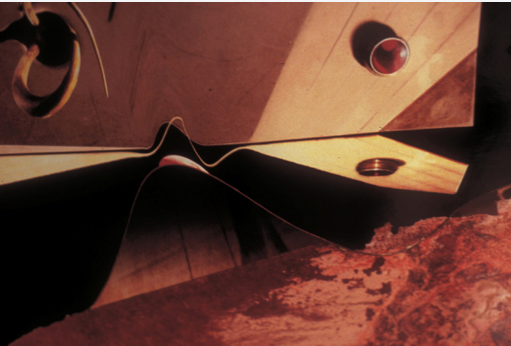
In the work shown here (Figures 1c-6c) the students found and used appropriated



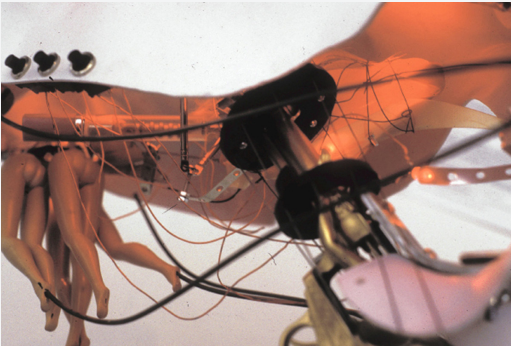
▲ Figure 1d Graphic Analogic Construct



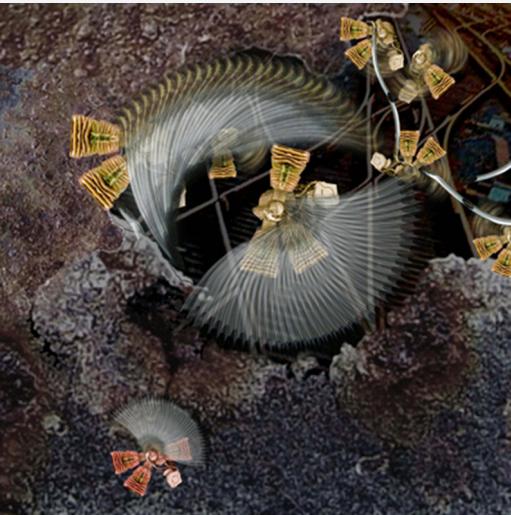
▲ Figure 2d Graphic Analogic Construct, Motel Desert House + Garden, Plan



▲ Figure 3d Analogic Construct Museum for Things RE(A)D



▲ Figure 4d Spatial Syntax Analogic Construct Museum for Things RE(A)D



▲ Figure 5d Motel of Multiple Psychologies Motel, Aerial View



▲ Figure 6d Motel of Multiple Psychologies Motel, Aerial View

material, downloads, or scans to produce a flat graphical surface - an image of a possible architecture, situated in the space of a found photograph: a painted ceiling; an aircraft carrier deck; a rock quarry. Sensitivity to the qualities of the given photograph and of the appropriated material assembled toward an architectural possibility was more important than the constructability, program legitimacy, or so-called content of the spatial proposition. It was suggested that the students might be collecting parts of many things that did not know what they could become collectively. Borrowing from analogic thinking - to help flesh out architectural possibilities, the overall formation might be something like a bagpipe crossed with a B-52 bomber with a dash of time-lapse photography tossed in for good measure. Or, the spatial formation might occupy the curtain wall surface like a corsage on a wedding dress, while moving like an Epson scanner with a stutter, only in the dark.

Analogic Means: Framing

Derived from the Greek *analogia*, this design accomplice operates through likenesses; that is, “this looks like that,” “this behaves like that,” “this is materially like that.” Analogous thinking can be a proactive ally for the architect, brokering deals with objects, events, and phenomena out of one’s design grasp, increasing the pool from which spatial potential might emanate. Analogous thinking can also break down categorical and disciplinary silos, opening up formal, material, and behavioral range for design opportunities. It is a colloquial design method, easily accessed, and it increases our design capacities a hundred-fold, at the flip of a switch. It is a design method that requires translation, because “this is only like that” - “this is not that.” The use of analogic production is a specific kind of appropriation where anything can be used as grist for the creative mill. This range includes fragments, wholes, and combinations of formal, material, behavioral, and operational attributes of a thing, an event, or even a conceptual structure.

Several interesting questions arise in the framing and use of this method, including questions about so-called authentic production, the (in)directness to architecture and challenges to legitimate subjects for architectural production. For many students, this particular method has proven to be enormously valuable, by increasing their material and formal vocabulary, or the potentials for both, remembering that as designers we often don’t yet know what things are, but we have some sense of what they might be like. For example, imagine that the section through a living space in a house is like a section through a French horn, the envelope for the space is clad in materials that are like the surface of a B-52 bomber, crossed with graffiti and the ground plane is like a circuit board crossed with the game of Monopoly.

In these examples (Figures 1d, 2d, 3d and 4d), there is a single image of an analogic construct, meant to provoke the imagination about where the likenesses might lead in the architectural or landscape proposal. In the last two cases (Figures 5d and 6d), the examples are images of an analogic construct on the left side, and the spatial translation or spatial proposition on the right.

CONCLUSION

“The term method has to have laid aside its modern and Cartesian intention of objectivity in order entirely to enter the service of the subjectivity that forms itself immanently. What had constituted its meaning for theory, its communicability, without any remainder, from individual to individual and from generation to generation is negated here. Method is precisely what the fathers always fail in and what grows out of opposition to them. For Rieme, Goethe explains this as follows: “Method is what belongs to the subject, since the object is, after all, familiar. Method cannot be handed down. An individual from whom the

same method is a need must find it for himself. Actually only poets and artists have methods, since what matters to them is to come to terms with something and to set it in front of themselves."

Work on Myth, Hans Blumenberg, 1985

Significant changes in cultural paradigms, global dynamics and the practice of architecture, and importantly, architectural education, suggest that versatility and conceptual broadening may be a viable alternative to increasingly dominant forms of specialization and schematic spatial production. Design method breadth is crucial toward this possibility. As mentioned, increased sensitivity to method involvement suggests a range of provocations for the architect, including the roles of the author; the purity of a given method in its implementation; the preferences and limitations of a method; how quickly any given method enables architectural results; and the representation, or material techniques that effectively provide engagement with any range of methods.

On the one hand, the conceptual range through which we understand architecture to be possible seems limited, necessarily by a range of legitimate concerns. On the other hand, investing in design methods might liberate the ways in which we imagine spatial potential. With the confidence of familiarity of diverse design methods and experience by implementing several of them - and their possible combinations, sequential choreography, morphing - one might also broaden the conceptualizations of architecture, broadening disciplinary knowledge on several fronts, including the changing roles of authorship, programmatic breadth, typological reframing, and technique expansion, to name a few. For example, with the confidence of a content to form design method, or analogy as a means for working, one could conceive an architectural approach for duplicating a domestic interior, sending the clone into the neighborhood to co-mingle with other houses. Or the daytime advertising façade of a Home Depot might reconfigure itself to become a nocturnal agricultural surface, or suburban backyards might regenerate themselves to become ecologies of fish markets at dawn and a bioluminescent electromagnetic field by night. If thinking about certain biological processes, or smart and self-generating logics, analogically, architecture could scan a site and diversify land use options whilst on the run. Or, architecture might grow, delete, and regenerate aspects of itself whilst morphing the regenerated parts into another form through activated self-learning response systems. If we were to deploy ventriloquism, again analogously, we might be able to materialize the virtual space of a building's construction rather than the building itself.

Varied situations in which an architect might work, do design research, or aimlessly probe curiosities also suggests varied, perhaps radically different, approaches to design. Designing parts of a new city in China might require different design methods in relation to design research invested in crossing metaphors, data, and narrative interests toward a spatial proposition. Or, working on transforming the ornamentation of the interior of a Las Vegas casino might be more effectively engaged by using design methods related to the interests of the project - rather than using the same design methods for a visionary project about floating bird motels, cloud harvesting, and bio-morphic interests.

I argue that we are likely to work in different circumstances, both real and speculative, over the course of our time in the discipline of architecture. In terms of real cultural agency and durability, it seems obvious that we might need to act differently in different circumstances. Diverse design method understanding could go a long way toward optimizing the intersection of the capacities of the architect, design methods, techniques for working, cultural and disciplinary contribution and the ultimate spatial production in

particular situations - represented or materialized.

Optimistically, we can position work and the means for working in relation to the ethical concerns of the architect, attempting to locate them discursively, culturally, and disciplinarily. Ultimately, investing energy in the scope of architecture - what it might take on ethically, culturally and situationally. The contributions of increased method awareness toward producing spatial make up play no small part in training the spatial imagination and the optimization of architecture's cultural power, grounded in creative participation. On one hand, it is shocking how teaching design method deployment has gone missing. On the other hand, our catatonic condition might be revitalized, using appropriation and biological processes in this case - using respiration as a metaphorical catalyst - once again breathing life into our beloved discipline and the cultural agency of architecture.

Hybrid design workflows of digital crafting and material computation

Soomeen Hahm, Igor Pantic

The Bartlett School of Architecture, UCL, UK

ABSTRACT

In this paper, we are presenting a number of research projects, which illustrate a design methodology developed by Research Cluster 6 (RC6) of The Bartlett's Graduate Architectural Design program, positioned on the overlap between the digital (agent-based design strategies and generative form-finding) and analogue computation strategies (material behaviour and crafting techniques). In that context, RC6's agenda argues for a new kind of craft, rooted in a thorough understanding of traditional, hands-on craft combined with expertise in contemporary computational concepts. In this regard, research presented in this paper primarily focuses on merging traditional, low-tech manufacturing processes with advanced technological approaches to design and realise new spatial concepts. Particular interest lies in novel combinations of analogue and digital methods in which hands-on and computer-controlled design and manufacturing operations do not just co-exist but overlap. The two projects presented in this paper, SanDPrint and FaBrick, address these premises through custom developed form-finding and fabrication processes, and test them through 1:1 scale prototypes.

INTRODUCTION

In this paper we discuss the design methodology and research approach carried out by the Bartlett GAD Research Cluster 6 (led by Daniel Widrig, Stefan Bassing and Soomeen Hahm). This is done through the presentation and breakdown of unique workflows, which re-evaluate the role of craft and hands-on production in the digital design domain under the umbrella of the "Crafting Space" agenda.

The research agenda of RC6 argues for a new kind of craft, rooted in a thorough understanding of traditional, hands-on craft combined with an expertise in contemporary computational concepts. The conducted research primarily focuses on merging the traditional, low-tech manufacturing processes with advanced technological approaches to design in order to realise new spatial concepts. In that sense, it is positioned on the overlap between the digital (generative form finding) and analogue computational strategies (material behaviour and crafting techniques). The emphasis here is on exploring the methods for overcoming the discrepancies between the top-down and bottom-up decision making processes, while exploring the benefits of previously mentioned different design inputs - material behaviour, generative agency or human/designers' input.

This was done through a series of individual architectural scenarios / research projects, which address these premises through custom developed form-finding and materialisation processes. These ideas as well as the resulting research and educational projects will be demonstrated in the paper. All of the proposals - prototypical structures, architectural objects and products - are built and tested in a 1:1 scale.

RESEARCH CONTEXT

With the advent of new digital design and manufacturing technologies, designers are working at a pace and resolution unimaginable just a few years ago. Digital systems allow designers to accumulate, structure and utilise massive quantities of information to parametrically shape products and the built environment. Likewise, the corresponding fabrication technologies, such as 3D printing or robotics, synthesise these projects in an increasing scale and resolution, employing rapidly expanding ranges of “digital materials”. While these software and hardware systems facilitate rapid design and production, tactile interaction with form and matter throughout the design and fabrication process is increasingly scarce.

Following the application of such systems, new sets of questions, constraints and concerns emerge. While we are now able to rapidly materialise almost any form, we are struggling with issues such as high cost of parts, limited material choice and large-scale applicability. In addition, fully automated fabrication systems often force designers into rather linear production pipelines with little room to manoeuvre or improvise. Since machining is expensive and time consuming, the actual process of making is often delayed to the very end of the design phase, usually delivering highly predictable, pre-simulated results. In such workflows notions of spontaneity, artistic intuition and noise are usually undesirable.

In this context RC6 seeks to explore hybridised design and fabrication models, in which tactile interaction with materials and form initiates and drives all research efforts. We embrace messiness as opportunity, and failure as part of the invaluable learning process. We are particularly interested in novel combinations of analogue and digital methods in which hands-on and computer controlled design and manufacturing operations do not just co-exist but overlap. With the research in such customised, semi-automated processes RC6 engages in the evolution of a new, crafted aesthetic, one that reflects a shift from an architecture predominantly interested in representation and tools towards an architecture that brings new notions of craftsmanship, intuition, and a post-digital design sensibility.

FABRICATION AND MATERIAL SYNTHESIS

A number of design and manufacturing disciplines, such as fashion, product and automotive design, are rapidly adapting to previously mentioned new fabrication technologies - particularly additive manufacturing or 3D printing of market-ready products. Noteworthy examples of this include works by fashion designer Iris van Herpen, who utilises rapid prototyping to produce couture pieces, as well as Nervous System - a design studio which works at the intersection of science, art and technology and utilises digital fabrication to create affordable art, jewellery and housewares. In contrast to this, rapid prototyping in an architectural context is still mostly reduced to being a fast and painless way of creating representational models, instead of using its potential for architectural production and to bring a new materiality into the architect’s increasingly virtual studio. This is at least partly due to the fact that, until recently, only the larger, commercial practices and institutions could afford this expensive equipment. The reduction in cost of these machines, coupled with the general democratisation of tools (soft- and hardware) will change this. The spread

of open source/DIY equipment, shared knowledge and innovation in the bypassing of patents both in terms of machine construction as well as the production of consumables now allows us to economically create complex parts, enabling smaller studios to utilise these systems.

Material research and material computation are often dealing with the post-construction lifecycle of the object. Their translation into computational models is limited to material property simulations within the closed linear system of design and production, missing the tactile interaction between the computer generated form and matter.

Likewise, the application of cutting-edge fabrication techniques such as 3D printing and robotic fabrication is often constrained to predefined modes of production. In such cases, the manufacturing technique is disconnected from the design process and used purely as a means of production of advanced and intricate geometries, without the direct feedback between the two. Examples of such application can be seen in the pioneering 3D printed work of Behrokh Khoshnevis at USC and Enrico Dini of D-Shape.

With the increasing affordability of 3D printers, and recent developments of affordable robotic arms (EVA by Automata Technologies), it is inevitable that such tools will become an integral part of RC6's two-fold approach. However, in spite of advanced material research and robotic fabrication booming recently (Achim Menges at ICD Stuttgart, Gramazio&Kohler at ETH, MIT Mediated Matter group), these avenues of design research are often disconnected. In the robotic fabrication process, machines are often used as end effectors, pre-programmed to deposit (extrude, cut, aggregate) the material as intended by the design, creating 1:1 representation of computer generated form. Robotic fabrication workflows should come from fabrication techniques and inherited properties and latent qualities of used materials, creating a feedback loop between machine and material limitations and properties, and the design, which evolves through received feedback.

GENERATIVE DESIGN TOOLS AND METHODS

With all of us more and more dependent on ready-made fabrication strategies, pre-made scripts and black box ("off the shelf") technology, an unbiased evaluation of our computational design culture is increasingly difficult. Within that context RC6 seeks to re-evaluate the role of craft and hands-on production in the digital design domain. This is done through continuous exploration in hybridised design and fabrication strategies in which digitally-controlled techniques of form-finding and manufacturing naturally blend with existing crafting techniques and low-tech ways of making.

In regard to application of off-the-shelf software packages in architectural practice and academia, Senske (2014) notices the importance of designer's thorough understanding of the used tools, where using off the shelf packages often results in designers using tools without comprehension of the inner working of the tools themselves.

There is no denying that algorithms are becoming an inseparable part in the processes of both the design and production of complex geometrical solutions. However, here the algorithmic approach is often used as optimisation strategy or for geometry rationalisation. Such examples can be seen in the work of Philippe Block and his research group at the ETH Zurich, which is efficiently using topological analysis algorithms in order to simulate and resolve structural issues in the design of shell structures. The project for Qingdao Cultural Centre by ZHA utilises rain-flow analysis algorithms as a means of phenomenological articulation. Here the perceptual identification of functional units and their relations are

facilitated by the surface articulation of the structural shells, derived from the algorithm. Examples of custom applications, such as processing libraries do exist within the design community - iGeo by Satoru Sugihara or Plethora by Jose Sanchez, to name a few. However, as elaborate as they are, parts of such libraries are either focusing on a specific design problem, or are not directly built around a specific design workflow.

DESIGN METHODOLOGY - TOOLS, GENERATIVE METHODS & AESTHETICS

Now in its third year, the RC6 - Crafting Space agenda argues for unique workflows, which form a seamless pipeline throughout the entire design process - from the initial concept stage to its fabrication. This comes as a result of a pursuit for new architectural aesthetics, which emerge from innovative way of thinking about material computation and fabrication, while at the same time searching for creative applications of available tool sets in combination with cutting edge technologies and computational powers. The resulting designs are derived from generative systems, which manifest the material behaviours. Manoeuvring between disciplines and techniques, RC6 seeks to occupy in-between territories where traditional and contemporary ways of designing and making blur into one.

HYBRIDISED WORKFLOWS

With this in mind, the presented design methodology combines top-down and bottom-up approach on one hand, and how manufacturing iterations and techniques feedback the computational models on the other. Here, computational models are not just representational, nor do they consist of material property simulations. In this sense, they are bound to fabrication logic and its constraints. Furthermore, they constantly feed back to the manufacturing process, effectively closing the design-to-manufacturing loop.

Throughout the year, RC6 traditionally works in multiple scales. With a particular focus on physical production, students gradually increase the scale and scope of their work through iterations of prototyping. Later stages of the research are dedicated to the development of a proposal in which material experimentation, applied prototyping, coding and modelling converge into a coherent architectural design proposal.

With regards to this, the proposed design approach is not technique biased. Meaning that we are taking an eclectic, multi-platform, multi-disciplinary approach, with the intention to hack into crafting techniques and corrupt digital workflows. In this sense, the research questions the following:

- Tactile interaction between digital models and physical products
- Black box technology and ready-made fabrication techniques
- The balance between the top-down and bottom-up approach, and the influence this balance has on the aesthetics of the product

In an attempt to achieve this, we are driven by material computation, material performance and its tectonics and the tactile feedback between the digital and physical. We are taking an holistic approach, where we look at the common methods between digital design and manufacturing processes, embedding the generative logic with fabrication constraints, resulting from analogue computation or machine/material limitations.

The analogue computation refers to exploration into material performance, physical manifestations of proposed systems and their tectonic protocols. The design systems are

firmly grounded in rigorous research on material behaviour, as well as in its formative and structural properties. From this material uncertainty and unpredictability of hybrid material systems, the true design research can emerge.

DESIGN APPLETS

Custom design applets, programmed in Processing, are developed to support design craft, and not a means for themselves, with the intention of closing the gap between digital simulation and fabrication. The goal was to create scenario specific applets/design engines, establishing the connection between initial inputs, which drive the design and its iterations, and previously mentioned design and fabrication constraints. This approach contrasts project specific scripts (one end of the spectrum) or black-box program packages, which are robust and overly 'open' (other end of spectrum).

As mentioned, the design process for each scenario was two-fold, addressing the fabrication techniques as the means of producing full-scale prototypes, and computational design techniques, which were guiding the design process and establishing generative logic. The computational techniques used in this process are primarily based on the application of multi-agent systems, as a means of achieving heightened control of architectural matter as well as producing novel spatial and formal outputs. Design applets are specifically designed for each of the testing scenarios, in order to respond to and engage with the selected fabrication techniques.

CASE STUDIES

The following chapter introduces student projects developed under the umbrella of the "Crafting Space" agenda. Projects developed within RC6 range from projects derived from a specific material or fabrication system to projects driven with a specific computational technique. While all of the projects address both material computation and application of generative design techniques, we can group the projects into 3 main categories, according to the dominant methodology that drives the process:

- Material behaviours
- Hybrid Material Systems
- Generative computational systems

However, this paper will focus on two projects that are centred around the investigation of material behaviour in conjunction with innovative engineering techniques. The point of departure in these two cases was an exploration into unorthodox material systems, rarely used within the building industry. Projects SanDPrint and FaBrick (which use sand and felt fabric respectively) illustrate the process in which such material system is driving the creation of an innovative construction method.

SANDPRINT

Starting from the interest in casting techniques using recyclable moulds, SanDPrint (Xiyangzi Cao, Shuo Liu and Zeyn Yang) conducted thorough research on a unique mould-making technique which uses rubber tubes and sand. The goal was to create an easily available and low-cost fabrication method, using abundant material in a way that is uncommon in everyday architecture practice, by simulating 3D printing with a low-tech crafting technique. Precedents of similar approach can be found in the works of Victor Castaneda, who developed a series of bowls made from casting plaster over naturally created divots, and Max Lamb, who adapted a primitive form of sand casting, filling the



▲ Figure 1 Fabrication Process // GAD RC6 / Team SanDPrint: Xlyanzi Cao, Shuo Liu & Zeyn Yang



▲ Figure 2 Process of removing the casted piece from the sand mould // GAD RC6 / Team SanDPrint: Xlyanzi Cao, Shuo Liu & Zeyn Yang

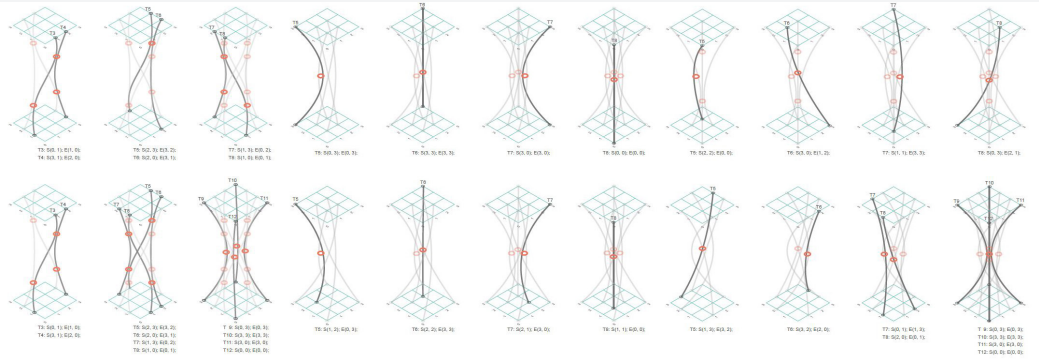
relief carved into the beach sand with molten pewter in order to create furniture pieces.

In the SanDprint fabrication process the mould is formed from wet sand, which is placed around the rubber tubes. Once the tubes are removed, a casting material such as plaster, concrete or metal is poured into the holes. The curvilinear nature of the rubber tubes, in combination with the fine texture which would be formed on the surface after the sand was removed, provided the design of high aesthetic qualities through an easily affordable low-tech fabrication technique (Figure 1 and 2). In addition to this, a removable frame was designed to stabilise and control the direction of the tubes.

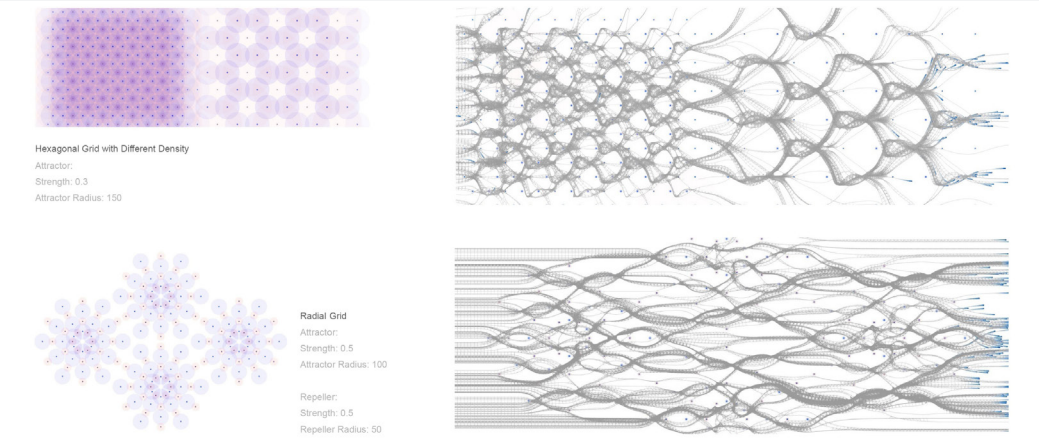
The rubber tubes had constant section, which in combination with rubber material flexibility and low friction allowed them to be extracted from the mould. Furthermore, the type of sand and grain size, as well as their combination with castable materials of different grains established the basic set of design constraints. Sand had to be of a grain small enough to capture the form created by the tubes, whereas the casting material had to be able to flow through the mould without blocking the tunnels. Likewise, the particle size and the drying speed of the sand affected the structural properties of the sand. In regard to the choice of casted material, parameters such as drying time, liquidity and permeability drove the decision towards plaster over resin, cement and a plaster and cement mixture.

Furthermore, the tubes themselves could be bundled only up to a certain point, since if the internal columns were to thick, the mould would internally collapse. In addition to this, specific tube curvature constraints were established. The tube curvature could not be too steep, as it would result in breaking the mould during the extraction process. These constraints – the angle of the branches and the number of branch generations - informed the digital models. Initially, this was translated into a generative process based on the logic of L-systems, which was used to generate the triple branching networked structures, which would later on be translated into tubes for fabrication.

Applying the mentioned constraints derived from the material system, a specific design language of bundled curves was developed. The patterning language was informed by three principal operations of tube cohesion, tube rotation and combination of the two (Figure 3). The digital system would take into consideration parameters such as the maximum number of bundles per column, minimal distance between bridging points, and curvature constraints. Based on the conclusions of initial digital studies, a more elaborate



▲ Figure 3 Tube patterning operations // GAD RC6 / Team SanDPrint: Xlyanzi Cao, Shuo Liu & Zeyn Yang



▲ Figure 4 Processing simulation and patterning study // GAD RC6 / Team SanDPrint: Xlyanzi Cao, Shuo Liu & Zeyn Yang



▲ Figure 5 Full scale SanDPrint column prototype // GAD RC6 / Team SanDPrint: Xlyanzi Cao, Shuo Liu & Zeyn Yang



▲ Figure 6 Interlocking column detail // GAD RC6 / Team SanDPrint: Xlyanzi Cao, Shuo Liu & Zeyn Yang

generative process was established, based on multi-agent systems. Here the agent behaviour was informed with the same constraints and parameters, while the tubes were derived from agent trails (Figure 4).

All of the furniture scale prototypes were designed with 1:1 parameters in mind, where the number of agents/trails and distance between them would take into consideration diameter of the tubes that were used in the fabrication process. Following this, larger scale structures were also further tested digitally. The size of the each fabricated object was essentially limited by the size of the supporting frame. In order to efficiently fabricate larger pieces, techniques such as distributed casting, continuous casting, as well as the interlocking of smaller casted components were tested (Figure 5 and Figure 6).

FABRICK

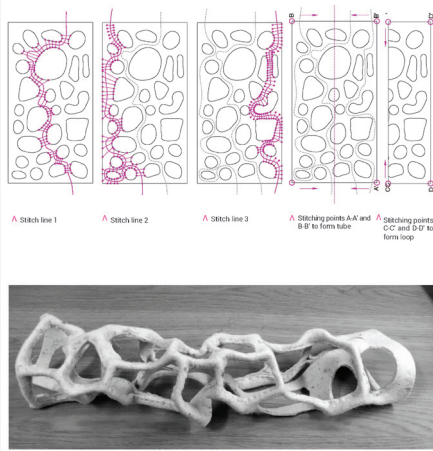
Inspired by the dramatic advances within the field of textile and fashion design, the FaBrick project (I-Ting Tsai, Somdatta Majumdar, Xixi Zhend, Yiru Yun) investigates the correlation between the development of new material craft in the form of couture architecture and the architectural design and fabrication process. With the idea of developing quick and easy methods for designing and fabricating space, this couture architecture project examines the wider implications of textiles in space creation, changing the way that fabric is perceived in architecture. The project links fabric manipulation processes, typically used in the fashion industry, with digital modes of design and fabrication, creating a new typology of fabric architecture.

Traditionally viewed as a flat and two-dimensional material, fabric has mostly been used in architecture as a surface sheet and roofing material, without fully exploring the material's versatility. With this in mind, FaBrick conducted research into a composite material system using felt fabric, and resin, with the fabric as primary structural material, rather than a secondary element to other components in the structural system. The material properties of felt were used to produce 3-dimensional structures from 2-dimensional sheet material by traditional stitching techniques. Softness and malleability of the fabric were used as an advantage in the process of forming complex geometrical shapes.

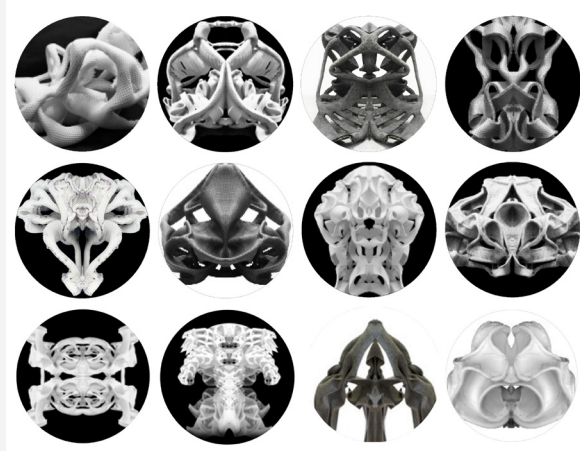
The fabrication process would start by cutting a pattern in the material and stitching the fabric along the cut seams (Figure 7). The shape of each prototype piece was created by cutting out sections from a flat sheet of fabric using a laser cutter. The fabric would then be stitched and folded into one of the three types of formal components (Figure 8):

- Surfaces and creases
- Holes and tubes
- Cut slits

Initially fabric would be moulded into pipe-like structures that could support the weight of the remaining material. After the rest of material is stitched and shaped the hardening material cures to create a completely self-supporting object. Here, different composites (mixtures with wood glue, resin etc.) can be applied to a single piece of material, creating varying levels of rigidity. This logic has been carried further as the main structural principle in the process of production of 1:1 prototypes (Figure 9 and Figure 10). Load-bearing elements would be folded into tubular sections, ensuring stability. The idea here was to create a continuously connected "structural skin", which gradually transitions from linear (tubular) elements, to surfaces and volumetric shapes. These elements would be further combined and reinforced with seams and ridges - transitioning from 2D to 2.5D elements.



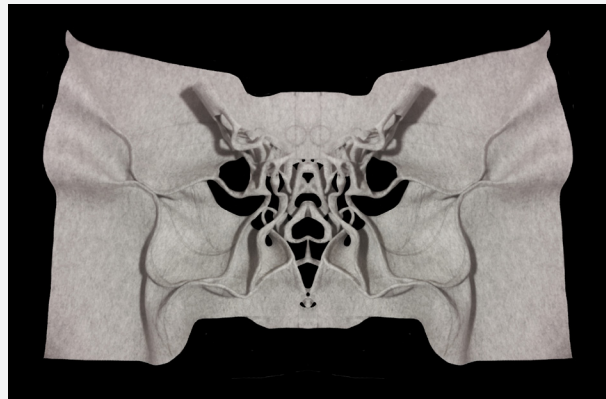
▲ Figure 7 Cutting pattern // GAD RC6 / Team FaBrick: I-Ting Tsai, Somdatta Majumdar, Xixi Zhend, Yiru Yun



▲ Figure 8 Catalogue of formal components // GAD RC6 / Team FaBrick: I-Ting Tsai, Somdatta Majumdar, Xixi Zhend, Yiru Yun



▲ Figure 9 FaBrick chair prototype // GAD RC6 / Team FaBrick: I-Ting Tsai, Somdatta Majumdar, Xixi Zhend, Yiru Yun



▲ Figure 10 FaBrick surface prototype // GAD RC6 / Team FaBrick: I-Ting Tsai, Somdatta Majumdar, Xixi Zhend, Yiru Yun

Further folding of the tubular and surface elements would result with 3-dimensional arrangements. This allowed for the creation of objects with varying surface and structural properties, depending on the applied formal components, as well as on strategic placement of rigidifying composite material.

The digital workflow itself was set up in order to develop two different aspects of the project in parallel - simulation of stitching and aggregation of smaller objects. Due to the size constraints it has become apparent that in order to scale-up, prototypes could not be made out of a single sheet of felt, but would rather be created as an assemblage of interconnected smaller pieces.

Simulation of high-resolution fabric is computationally very expensive, and reducing the resolution of digital models would result in loss of complexity in comparison with the physical experiments. With this in mind, it became apparent that a hybrid approach of multiple digital strategies (combining generative and explicit modelling) and constant

feedback between digital and physical models based on material limitations is of absolute necessity. This directly influenced the digital simulations, which focused on developing the relationship between two-dimensional patterns of felt sheets and three-dimensional geometry, through simulation of folding and stitching behaviours. This relationship between the two-dimensional patterns and the resulting 3D geometry, as well as the design language of travelling seams which would act as the connections between smaller components, presented the basis of the FaBrick digital design repertoire, where different digital techniques were used for simulating different formal components. While surfaces and slits were treated with fabric simulation engine and generative methods were established for creating of tubes and holes, slits and seams were generated through explicit modelling techniques.

CONCLUSION

The presented projects illustrate the importance of closely integrating digital crafting techniques with fabrication protocols, as well as the importance of establishing constant feedback between the two. This can effectively be achieved through the use of custom design applets that take the design methodology as the common denominator for the two ends of creative process. This approach creates a general framework for design research without being overly prescriptive, allowing for the unexpected and novel outcomes to emerge.

While navigating between digital and physical worlds, the approach of crafting agency is able to produce results of high complexity and resolution, while being able to offset the imprecisions in the manufacturing process, unlike the standard linear fabrication processes. This comes as a result of embracing the noise and failure as integral part of the design process, which combines analogue and digital modes of production as inseparable parts of complex design ecology.

CREDITS

The presented projects were developed within Bartlett GAD Research Cluster 6 Crafting Space agenda, during 2013/14 (SanDPrint) and 2014/15 (FaBrick) school years.

- Bartlett GAD RC6 tutors: Daniel Widrig, Stefan Bassing & Soomeen Nahm
- Team SanDPrint: Xiyangzi Cao, Shuo Liu & Zeyn Yang
- Team FaBrick: I-Ting Tsai, Somdatta Majumdar, Xixi Zhend & Yiru Yun

REFERENCES

- Choma J (2010) Contested Boundaries: Digital Fabrication + Hand Craft, in N.Leach, D.Turnbull, and C.Williams (eds.), Digital tectonics, Wiley, London: 70-77
- Henriques GC (2009) Crafting New Artefacts: Expressing the changing condition of nature, culture and technology, in Proceedings of the 14th CAADRIA Conference, Dunlin: 215-224
- Leach N (2004) Swarm Tectonics, in N.Leach, D.Turnbull, and C.Williams (eds.), Digital tectonics, Wiley, London: 70-77
- Senske N (2014) Digital minds, materials and ethics: Linking computational thinking and digital craft, in Rethinking Comprehensive Design: Speculative Countercultures, Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2014, Hong Kong: 831-840
- Schumacher P (2014) Tectonic Articulation - Making Engineering Logics Speak, in M.Garcia (ed.), AD: Future Details of Architecture, Wiley, London
- Sugihara S (2014) iGeo: Algorithm Development Environment for Computational Design Coders with Integration of NURBS Geometry Modelling and Agent Based Modelling, in Design Agency: Proceedings of the 2014 Association for Computer Aided Design in Architecture (ACADIA), Los Angeles: 23-32

Research-based teaching as a search for novelty in architectural education

Derya Yorgancioğlu

Istanbul Kemerburgaz University Dept. of Architecture, Turkey

ABSTRACT

This paper argues that a reconsideration of architectural education as a project may enable us to articulate teaching and learning processes as research practice itself, which aims at the development of new possibilities of architectural creation and the generation of architectural knowledge. In this paper the term project is used not in merely architectural terms but rather as a search for novelty, the main motivation of all kinds of architectural creation. Novelty is emphasized as a precondition of architectural creation, as architecture is always about the new, beyond the established.

The paper inquires teaching and learning practices in architecture as interconnected processes in which knowledge emerges as a result of a search for novelty. It is underlined that novelty may emerge when research-based knowledge enmeshes with experience-based knowledge in architectural education. The debate on teaching and learning in architecture as a search for novelty dwells upon three main topics: (1) reflection in teaching and learning (2) teacher-student dialogue, and (3) theory-practice nexus in architectural education. Firstly, the paper examines how reflection on theoretical knowledge and experiential knowledge influences our learning and understanding of the teaching and learning processes, the methods, tools and outcomes in architectural education. It is discussed that reflection is needed not only on knowledge about teaching and learning, but also on how that knowledge is acquired. Secondly, the paper focuses on the role of the student as the active subject of learning process, and that of the teacher as an adult learner, researcher and an advisor to the student. Thirdly, the paper stresses on the ways new experiences generates new knowledge and new knowledge leads to the development of skills and expertise for teachers. The paper finally asserts that in the condition that the teacher as practitioner, learner and researcher acts as the generator of new architectural knowledge and experiences, experience-based knowledge and research-based knowledge merges on the basis of project-based knowledge in architectural education. When we reflect on and call into question our thinking and practice of architectural education, teaching and learning becomes under continuous review and transformation, generating new knowledge and revealing new conceptions and insights for architectural education.

INTRODUCTION

The need to reconsider university education as a comprehensive process is at the center of debates in higher education, since the formation of “*communities of learning, dialogue, research, and practice*” is seen as the primary mission of a modern university [Pardales and Girod, 2006; Mavroskoufis, 2012]. The

position of architectural education as a form of professional education at the university context deserves a special attention within the framework of these debates. By emphasizing the comprehensiveness of architectural education, this paper investigates research-based teaching as a search for novelty in architectural education.

The development of graduates as competent practitioners, promising architects, and well-equipped individuals are essential goals of professional education in architecture. The pattern of teaching in professional education is different from other forms of teaching. The intertwining of specialized knowledge and technical expertise with a capacity for analytical, critical and imaginative thinking is the ground on which architectural education is situated. Within this framework, architectural learning and teaching develop as forms of doing that occur in experience. Learning by doing, inquiring, experimenting and synthesizing are the prominent tools employed. A learner-centered educational approach is indispensable. Learning environments as such becomes places in which the encounter of students with academics occurs in dialogical and collaborative ways. Learning environments in schools of architecture rely heavily on collective engagement of both academics and students in research throughout the educational process, which primarily aims at revealing the potential abilities and competences of learners rather than transferring knowledge. Research-based teaching and learning as reciprocal activities are at the center of architectural education.

In this paper the term research-based is used in the sense that Ron Griffiths (Griffiths, 2004) puts it:

“... the curriculum is largely designed around inquiry-based activities, rather than on the acquisition of subject content; the experiences of staff in processes of inquiry are highly integrated into the student learning activities; the division of roles between teacher and student is minimized; the scope for two-way interactions between research and teaching is deliberately exploited”.

Research-based teaching encourages students to learn through inquiry when the act of teaching transcends the transmission of knowledge and becomes a process of continuous investigation and reflection in which the teacher continuously learns. A dialogue and interaction between the teacher and students is essential. Research-based teaching aims at cultivating students with the knowledge, skills and attitudes they need to learn how to learn. At the same time, learning how to teach becomes a process of self-discovery and self-empowerment. In other words, teaching becomes a new task to learn. Students, on the other hand, should take more active and efficient roles in the learning process. In research-based teaching, the emphasis is more on the process and problems engaged with, rather than the product (Healey, 2005).

Taking the notion of research-based teaching as its starting point, this paper aims to open discussion on architectural education as a project. It argues that to reconsider architectural education as a project may enable us to articulate teaching and learning processes as research practice itself, which aims at the development of new possibilities of architectural creation and the generation of knowledge. In this paper the term project is used not in merely architectural terms but rather as a search for novelty. Novelty is emphasized as a precondition of architectural creation of all kinds. Architecture is always about the new, beyond the established. It generates a curiosity to explore the multilayered nature of problems in the built environment. Architecture opens “new ways of seeing and depicting the world,” to use the words of Michael North (North, 2013). It would not be a

misinterpretation to say that economic, political, social or cultural changes also change the responsibilities of the architect, the nature of knowledge and the ways of approaching knowledge. Architectural education gives space to curiosity and familiarity at the same time, while promoting a search for novelty. Novelty in architectural education derives from the attempts to advance knowledge needed to develop architecture as a discipline. The development of academics and students as active participants of a community of learners also makes contributions to go beyond the established.

Three primary components of architectural education as a project can be defined as (1) the teacher, (2) the student and (3) pedagogy (Spiridonidis, 2014). An analysis of how these components interact with each other may help better understand how architectural education acts as a project. In this paper it is argued that teacher-student-pedagogy interaction informs the ways teaching and learning and research informs each other.

Different conceptions of knowledge inform the ways research is conceived. There are varying conceptions about the nature of knowledge and research. Accordingly, teaching and learning are defined in numerous ways, and there are differing discussions regarding the roles of teacher and student within teaching-learning-research nexus. This paper underscores that by its very nature research is practiced through teaching and learning experiences of all actors involved in the process of architectural education. The paper also attempts to re-contextualize the teaching-learning-research nexus in architectural education into the debates on the notion of scholarship. As underlined by Angela Brew (Brew, 2003), “[d]ifferent ideas about the nature of research, scholarship, teaching and knowledge have different consequences for how we bring teaching and research together”. Scholarship, defined as the essential basis of the academic communities of practice, opens a fertile ground for any attempt to reconsider the roles of both teacher and learner as researchers in the process of architectural education. Architectural education is a community of teachers and students who continuously learn from each other and generate new knowledge through their joint effort.

THE NATURE OF RESEARCH IN ARCHITECTURAL EDUCATION

In the view of Ron Griffiths (Griffiths, 2004) “systematic process of investigation”, “advancement of knowledge” and “opening to the public” are the main requirements of any research act. He mentions:

“To count as research, an act of inquiry or ‘finding out’ is generally expected to involve a systematic process of investigation - i.e. one that is carefully designed and executed with regard to relevant methodological principles. It is also expected to be aimed at advancing knowledge within the field of inquiry, and not just acquiring information that is new to the inquirer or needed for an immediate practical task. The findings and the methods are expected to be made public, so that their validity, and their contribution to the existing knowledge base, can be assessed by the wider community of experts in the field”

(Griffiths, 2004).

This definition has important implications for the conception of research-based teaching as a search for novelty in architectural education. The ‘finding-out’ nature of research act should not necessarily imply uncovering what already exist, or bringing into light that which has already been established. It also implies the development of the ways to look through new perspectives and possibilities. This sheds light on the informative nature of research and establishes the connection of research with teaching and learning

experiences occurring in the education process. This connection is summarized by Burton Clark (Clark, 1997) in the following words: “[r]esearch activity can and does serve as an important mode of teaching and a valuable means of learning”. It is evident that the conception of research under consideration is not on an “atomistic” one “where the intention is to produce an outcome”; but rather it is based on an “holistic” conception of research “with an orientation towards internal processes and where the intention is to understand” (Brew, 2003; Brew, 1999; Brew, 2001). The second position regarding the nature of research brings to mind the Humboldtian idea of Bildung. Bildung manifests a “community of learners” in the university where “the experienced professors and the inexperienced students participate”, “students become familiar with new findings” and all kinds of teaching activity aim to support “students’ independent pursuit of understanding and knowledge, more than means of transmitting or imparting knowledge” (Dysthe and Webler, 2010).

Besides the holistic underpinnings of research emphasized above, there are differences in approaches that stem from diverse disciplinary perspectives. The varying nature of disciplines and their distinctive conceptions of knowledge, the modes of effective teaching and learning in different disciplines, different forms of pedagogy and curricula all shape the ways in which research is conceptualized and practiced by members of different disciplines. As it is argued by Griffiths (Griffiths, 2004) the differences in the ways that “forms of inquiry can be integrated into student learning activities” derive from the existence of “a number of distinct “modes of knowledge production” or “ways of making knowledge” that are manifested in disciplines. There are “disciplinary spaces” that can be defined as “the environment associated with different disciplinary cultures in which research and teaching take place,” and these disciplinary spaces shape the ways that research, teaching and learning experiences interact (Healey, 2005).

Architectural education as a university-based professional education has its distinct ways of how knowledge is constructed within the educational process. The main goals of research in architectural education encompass the building of collective knowledge and advancement of educational quality by improving student learning. The process itself is as important as the product of research. This is related with the disciplinary nature of research in architecture.

In *Charter for Architectural Research: A Declaration and a Framework on Architectural Research*, prepared by EAAE- Research Committee in September 2011, architectural research is defined as the “original investigation undertaken in order to generate knowledge, insights and understanding based on competencies, methods and tools proper to the discipline of architecture.” In this declaration emphasis is placed on direct and indirect support of architectural research to education through “research training of future architects” as well as “the continual advancement of the discipline”:

“... The aim of architectural higher education is to develop a research disposition in students. As future architects they need to be able to establish basic premises, perform critical analysis, conduct intensive research and propose syntheses independently. The architectural school as a whole and the design studio in particular are places for research practice par excellence”

(Charter for Architectural Research, 2011).

In reconsidering architectural education as a project, emphasis is placed on the nature of project as a process. This process brings together cognition and experience, thought and action. Architectural education should be designed as a process composed of interrelated

phases that help generate an interaction between the subject and the object. Jean-Pierre Boutinet (Boutinet, 1990) uses the term project as “an educational process summoning the individual’s potential and motivations.” Architectural education is a “project” in the sense Boutinet uses the term. The educational merits of this project stems from its potential to cultivate and improve intellectual and experiential knowledge, skills and attitudes of both teachers and students as interrelated actors of this process. What is at issue is not knowledge and understanding for their own sake. Construction of knowledge intertwines with the formation of different ways of teaching and learning. The enmeshing of knowledge produced through varying experiences of teaching and learning leads to novelty. In this way, architectural pedagogy becomes a continuous search and readjustment.

TEACHING-LEARNING-RESEARCH NEXUS IN ARCHITECTURAL EDUCATION

Teaching as an act of constructing knowledge through an interaction between the teacher and the student is the prevalent pedagogical approach in architectural education. This occurs as a dialogical process in which the role of the student is not that of a passive receiver, but of an active participant. The teacher acts as a tutor or mentor responsible for generating effective strategies and environments for learning. In order to achieve this, teachers should reflect on their own learning experiences. They should design the instructing process in a way to improve their teaching capacity, since teaching itself needs practice. In this way the act of teaching becomes an act of research that paves the way for new experiences of learning.

In the literature, numerous studies address different conceptions of teaching that derive from different conceptions of knowledge. A notable dichotomy stems from two opposite approaches to teaching: an “information transmission/teacher focused” approach to teaching versus a “conceptual change/student focused” approach to teaching (Trigwell and Prosser, 1996; Brew, 2003). While the first approach is based on a conception of knowledge as “objective and separate from knowers”, the second approach signifies the idea that “knowledge is more likely to be a process of construction” (Brew, 2003). According to an “information transmission/teacher focused” approach to teaching, research is a form of knowledge generation and teaching is a way of transmitting the knowledge generated through research. This understanding degrades the roles of both teachers and students. Teachers are portrayed as transmitters of pre-existing knowledge, while students become passive and homogeneous subjects ready to receive that knowledge. On the other hand, both teachers and students are attributed more active roles in the “conceptual change/student focused” approach to teaching. This approach is made apparent in pedagogical orientations such as critical pedagogy or transformative pedagogy. As noted by Ashraf Salama (Salama, 2009) critical pedagogy encourages the construction of new knowledge “through the dialogical process of learning” in which “the experiences of both students and teachers” are constructive. In a similar vein, transformative pedagogy supports “critical inquiry and knowledge acquisition, assimilation, and production in a manner that encourages students and educators to critically examine traditional assumptions and to encounter social and environmental issues” (Salama, 2009). Commitment to creativity, innovation, and continuous learning is the grounding principle of teaching both in critical pedagogy and transformative pedagogy. What is evident both in critical pedagogy and transformative pedagogy is a cyclical process in which critical inquiry leads to new understandings, new understandings lead to new experiences paving the way for new learning. In this way learning becomes a process of continuous development both for teachers and students as learners.

The prevalent approach to learning that informs both critical pedagogy and transformative pedagogy is “inquiry-based learning.” Learning by doing, experience-based learning, active learning and collaborative learning are all activities involved in inquiry-based learning. Involvement is for all modes of learning; the involvement of the student in the learning process that is also a research process. This involvement results in *“acquiring skills and attitudes that permit students to seek resolutions to questions and issues while they construct new knowledge”* (Salama, 2009). It is not only the student but also the teacher who is involved in this learning process. In the words of Le Heron (2004), both the teacher and the student become “co-learners” in inquiry-based learning processes. All these discussions can be re-contextualized into the older tradition of experiential learning raised in the seminal works of Dewey, Lewin, and Piaget, for whom “learning is most effective, most likely to lead to behavioral change, when it begins with experience, and specifically problematic experience” (Osterman and Kottkamp, 1993).

There are diverse forms of learning in architectural education that varies from theoretical learning to hands-on experience, as it is revealed mainly in the architectural design studio. An architectural design studio, portraying the particularity of design education, offers an integrative learning environment in which students encounter the technical, aesthetic, economic, social, or cultural aspects of architecture through a design problem generated from real-world problems. This environment encourages students to develop creative and reflective habits of thought and action. Informed by a student-centered pedagogical approach, the design project heads collaborative learning experiences as well as individual learning. It is this inquiry-based, active, experiential and reflective nature of design education that underpins Donald Schön’s argument of architectural learning as a “reflective practice” (Schön, 1983, 1987). Schön criticizes the persistent approach in technical rationality that depends on the idea that students learns a “body of theoretical knowledge...” and subsequently, that practice was “...the application of this knowledge in repeated and predictable ways to achieve defined ends” (Usher, 1997). The criticism raised by Schön seems highly relevant for architectural education in which theory and practice, knowing and doing can hardly be dissociated from each other. There is no one-way relationality between theory and practice in architecture. The idea that theory is the basis of practice, and that practice uses the theory produced apart from, it falls short of understanding the nature of the cyclical processes of knowledge generation in architecture. Architecture as a form of “praxis” entails the active engagement of the subject into the processes of all kinds of architectural creation, let it be in educational settings or in professional practice (Koutsoumpas, 2007a; Koutsoumpas, 2007b). These characteristics of knowledge generation are apparent in the processes of architectural education as well.

Architectural education, as a form of professional education, can be defined as a praxis in which thought enmeshes with action. Architectural education as praxis generates theory-in-action. We continuously learn architecture by doing it, by designing; furthermore we learn how to teach architecture by teaching. The learning environments in architectural education support students’ encounter with real-world problems, experiences of experiential and engaged learning. They also stimulate a dialogical and participatory relationship between teacher and student. For the teacher who acts also a learner, teaching architecture becomes a process of continuous learning. It is essential to create learning environments that build knowledge and reflective experiences both for students and teachers. Both parties have more active roles and the responsibility for the success of learning. In the words of Karen Osterman and Robert Kottkamp (1993), *“each of whom brings knowledge and expertise to the situation—become collaborators working on a shared task.”*

CONCLUSIVE REMARKS: SCHOLARSHIP AS A GROUNDING PRINCIPLE FOR RESEARCH-BASED TEACHING

The literature on the notion of scholarship should be addressed as a fertile ground for the debates on the interconnectedness of research and teaching in architectural education. The seminal work of Ernest L. Boyer at the Carnegie Foundation for the Advancement of Teaching opens new avenues for the discussion. In his report *Scholarship Reconsidered: Priorities of the Professoriate* [1990] Boyer underscores “teaching” as one of the four areas of scholarship in higher education along with “discovery”, “application”, and “integration.” This report not only challenges the “accepted hierarchy of research, teaching and service in the academy,” but also calls for a reconsideration of the scholarship of teaching that recognizes and rewards the “efforts to establish critical and rigorous cultures of teaching, and student support within the academy for the enrichment of learning communities” (Holgate and Sara, 2013).

As underlined by Boyer, teaching is a scholarly activity. Teaching becomes a scholarly activity when it is well designed as a process open to critical re-evaluation and development. Teaching should encourage students to develop creative and critical thinking skills by supporting active and experiential learning. Teaching practiced as a research process opens the possibilities of the teacher to reflect on his/her own experiences. Teaching as such moves from the transmission of knowledge towards the construction of new knowledge through reflective learning. This necessitates a change in understanding regarding the traditional hierarchy between the teacher and the student. The scholarly teacher, consistent with Boyer’s definition, is eager for lifelong learning. This understanding of scholarship of teaching calls attention to “critical inquiry into how student learning can be promoted, both in generic terms (i.e. general educational principles) and in relation to particular subject fields” (Griffiths, 2004). There is a need for architectural education to place greater emphasis on pedagogies that integrate research and teaching as modes of active learning, both for teachers and students.

Accordingly, teaching as a scholarly activity promotes bringing together of learning and research as an academic attitude and ethical gesture. At this point, once again reference should be made to Boyer’s conception of scholarship signifying a sense of community. Boyer insists on academic communities of practice as the grounding principle of scholarship. Being a community necessitates the presence and active participation of all members of academic departments, or disciplines -the students, academics and also professionals. These participants should be engaged in critical inquiry of the known and established, and be open to unplanned and beyond the established. Consequently, teaching and research comes together on the basis of critical scrutiny that leads to learning. This in turn fosters personal growth and development.

As research-based teaching is redefined to include the forms of knowledge generation that stem from inquiry-based and experiential learning activities, developing a framework for knowledge generation through teaching architecture becomes a significant contribution. Research-based teaching has the potential to generate learning experiences through which we, as teachers, learners and researchers, can make contribution for the enhancement of the discipline of architecture.

REFERENCES

- Boutinet, J-P. 1990. *Anthropologie du projet*, Paris: Editions PUF, Collection ‘Psychologie d’Aujourd’hui’.
- Brew, A. 1999. Research and teaching: changing relationships in a changing context. *Studies in Higher Education*, 24(3), pp.291–301.

- Brew, A. 2003. Teaching and research: new relationships and their implications for inquiry-based teaching and learning in higher education. *Higher Education Research & Development*, 22(1), pp.3-18.
- Brew, A. 2001. Conceptions of research: a phenomenographic study. *Studies in Higher Education*, 26(2), pp.271-285.
- Boyer, E.L., 1990. *Scholarship reconsidered: priorities of the professoriate*. Princeton, N.J.: The Carnegie Foundation for the Advancement of Teaching.
- Clark, B. R. 1997. The modern integration of research activities with teaching and learning. *Journal of Higher Education*, (68), pp.242-255.
- Dysthe, O., Webler, W. 2010. Pedagogical issues from Humboldt to Bologna: the case of Norway and Germany. *Higher Education Policy*, (23), pp.247 - 270.
- EAAE Research Committee, 2011. Charter for architectural research: a declaration and a framework on architectural research. [pdf] Leuven - Belgique. Available at: <http://134.58.106.10/web_data/documents/research/proposalCharter2011.pdf> [Accessed 10 May 2014].
- Griffiths, R. 2004. Knowledge production and the research-teaching nexus: the case of the built environment disciplines. *Studies in Higher Education*, 29(6), pp. 709-726.
- Healey, M., 2005. Linking research and teaching: exploring disciplinary spaces and the role of inquiry-based learning. In: R. Barnett, ed. 2005. *Reshaping the university: new relationships between research, scholarship and teaching*. McGraw Hill / Open University Press. pp.67-78.
- Holgate, P., Sara, R. 2013. Towards a teaching commons for architecture: the scholarship of teaching and learning in architectural education. In: (Un)common currency. AAE2013, Conference 4-5 April 2013, Nottingham Trent University, UK. <<https://architecturaleducators.files.wordpress.com/2013/12/holgate-2013-towards-a-teaching-commons-for-architecture-the-scholarship-of-teaching-and-learning-in-architectural-education.pdf>> [accessed December 2015].
- Koutsoumpas, L. 2007a. The switch of ethics and the reflective architect: in-between practice and theory. In: *Reflections on Creativity: Exploring the Role of Theory in Creative Practices Conference*, Duncan of Jordanstone College.
- Koutsoumpas, L. 2007b. Reconciliatory praxis: bridging ethics and poetics in the design studio, In: *Reconciling Poetics and Ethics in Architecture Conference*, McGill University, Montreal, 13-15 September, 2007.
- Lee, R. 2004. Research and teaching: making - or breaking - the links. *Planet*, (12), pp.9-10.
- Mavroskoufis, D. K., 2012. Teaching and learning in higher education. In: C. Spyridonides ed., *Improving learning quality in architectural education environments*, 15th Meeting of Heads of Schools of Architecture. Center for Mediterranean Architecture, Chania - Crete, 1-4 September 2012.
- North, M., 2013. *A history of the new*. Chicago and London: The University of Chicago Press.
- Osterman, K.F., Kottkamp, R.B. 1993. *Reflective practice for educators: improving schooling through professional development*. Newbury Park, CA: Corwin Press.
- Pardales, M., Girod, M. 2006. Community of inquiry: its past and present future. *Educational Philosophy and Theory*, 38 (3), pp. 299-309.
- Salama, A. M. 2013. Seeking responsive forms of pedagogy in architectural education. *Field Journal*, 5(1), pp. 9-30.
- Schön, D. A., 1987. *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions*. San Francisco: Jossey-Bass.
- Schön, D. A., 1991, first edition 1983. *The Reflective Practitioner: How Professionals Think in Action*. London: Basic Books.
- Spyridonidis, C., 2014. Better left unsaid? airing some latent truths in architectural education. In: *International Conference on Unspoken Issues in Architectural Education*. Cyprus, 3-4 April 2014, Eastern Mediterranean University (EMU) Faculty of Architecture.
- Trigwell, K., Prosser, M. 1996. Changing approaches to teaching: a relational perspective. *Studies in Higher Education*, 21(3), pp.275-84.
- Usher, R., Bryant, I., Johnston, R., 1997. *Adult education and the post-modern challenge*. London: Routledge.

Between design and digital: bridging the gaps in architectural education

Shelby Doyle & Nick Senske

Iowa State University, USA

INTRODUCTION

Developing technologies, such as computational design and digital fabrication, are transforming the design and construction of contemporary architecture. Today, architecture schools are tasked with introducing digital technologies as they are changing, creating an opportunity to develop innovative curricula and democratize access to these skills. However, the understanding of how to teach digital technology as an essential design skill has not kept pace with these rapid changes. Design education and digital technology education continue to be seen as separate loci of learning, separated by pedagogical gaps and teaching mindsets.

The aims of this paper are to take control of the pedagogical agenda for digital design in architectural education by debunking the myth of the digital native and to apply proven educational research to the pursuit of digital design. Two pedagogical proposals are put forward: learning objectives and soft skills for digital design in architecture. To be clear, this paper is a discussion of architecture, design, and education; not an argument for software and computer use in design. The relevance of this educational conversation extends only so far as it impacts the development of the profession's relationship to digital technologies as these technologies are changing. The goal of this, and any, educational proposal for architecture must be improving the state of architectural design in addition to advancing learning in both the academy and the profession.

Much of architectural education today is what Bruner calls "folk pedagogy", guided by implicit assumptions but not connected with educational theory or evidence beyond one's experiences (Bruner, 1996). This places the architectural discipline in an unfortunate position where it neither benefits from nor makes contributions to the larger conversations occurring in educational research. In the past three decades, advances in cognitive learning theory and psychology, supported by empirical evidence collected from rigorous classroom assessment, have brought science into the art of teaching. This paper applies principles from educational research to improve digital design instruction by bridging the gaps between studio learning and technology (digital) learning. The first section of this paper describes learning objectives and Bloom's

Taxonomy as tools of educational research designed to create clarity, transparency, and accountability among educators. Articulating learning objectives that are specific to digital design in architecture frames a conversation as to why there is such inconsistency and disagreement about the requirements of digital education across architectural curricula. The use of learning objectives may seem obvious or unnecessary if one is only considering their use in one's own syllabi, but in terms of disciplinary alignment, digital design instruction could benefit from the additional clarity offered.

The second section of this paper describes a list of soft skills that support students as they learn digital design followed by several methods for integrating soft skills into digital design instruction. Soft skills are "soft" in contrast to more easily quantifiable "hard" skills such as operating a machine or knowledge of art history. Failure to acquire soft skills such as resourcefulness, good electronic communication etc. negatively impacts how technology is introduced, practiced, and developed in architectural studio culture. With the rapid pace of technological change, students need to be comfortable with and capable of learning, relearning, and integrating new programs and tools throughout their career. Soft skills provide a framework for helping students develop this mindset and facility.

BETWEEN DESIGN AND DIGITAL

Computer-Aided Drafting and Design (CADD) technologies have become commonplace in architectural practice as tools of efficiency and production. For these very reasons the introduction of CADD in early architectural curricula has been fraught with anxieties along a continuum: from the undoing of creativity through positivist and reductionist logic (Pullasmaa, 1996) to a firm belief that these technologies will revolutionize the way architects practice and think about design (Kieran and Timberlake, 2003). At the same time, there is a presumption that students who have grown up with digital technologies are "digital natives" who possess special aptitudes or insights which are disruptive to learning computing. The presence of these anxieties and biases often leads to gaps in architectural pedagogy, as digital tools are misunderstood and misappropriated by students and teachers alike.

Digital design is a term in common use, however its definition is unclear. On the one hand, there is very little architectural work today which does not use the computer in some capacity, and yet there are also designs which consciously engage in digital aesthetics and processes. The latter is obviously digital in aesthetic, but the former could still be considered digital by method. The very existence of the category of digital design is problematic because it implies two cultural silos in architecture: those who are digital and those who are not. This outlook potentially limits students' educational and professional development.

Design is the verb in architectural education and in architecture; it is what architects do. For the purposes of this paper, *digital design* refers to the use of the computer and computer-driven tools (such as CNC machines, robots, etc.) when one designs architecture. The key is not what a person designs, rather whether that person employs the computer or not as a tool in architectural work. This paper interprets digital design as a broad skillset that should be available to all students, rather than

a niche specialization.

It is necessary to create the distinction between design and digital design – and to speak of teaching digital design – in this moment, because the introduction of the computer in architecture changes both what and how architects design. It introduces both new capabilities and new sources of bias and error. Therefore, it is necessary for architectural education to address and teach specific ways of designing with the computer – not how to use software or operate machines, but how to *design digitally*.

THE MYTH OF THE DIGITAL NATIVE

The common belief that students are self-regulating when it comes to learning and using technology may come from the notion of digital natives. The label “digital native” derives from a series of articles written by the technologist Marc Prensky during the early 2000s. Prensky describes the generation of young people born since 1980 as “digital natives” due to what he perceives as an innate confidence in using new technologies such as the internet, videogames, mobile telephones and “*all the other toys and tools of the digital age*” (Prensky, 2011). Enrique Dans counters Prensky’s claims: “*Simply being born into the internet age does not endow one with special powers. Learning how to use technology properly requires learning and training, regardless of one’s age.*” Dans goes on to expand upon the issues of assuming students do not need to be taught to use technology thereby becoming “digital orphans”, lacking in any model to copy or experiences that might have generated criteria for understanding (Dans, 2014).

For this reason, beyond basic fluency, architectural instructors are uniquely positioned to model substantive content creation and healthy critical thinking about these technologies. By perpetuating the myth of the digital native, architectural education is missing the opportunity to establish strong pedagogical foundations from which future digital advancements will emerge.

PEDAGOGICAL ALIGNMENT AND THE VALUE OF DIGITAL DESIGN

The lack of agreement and clarity among schools regarding digital design creates problems for the discipline. How can a skillset be taught without a clear definition? And how can the field evolve when there is such contention over education in a critical area? Dialog and common ground are needed.

A key reason for the confusion surrounding digital design instruction in the university setting is a misunderstanding of its educational value as a set of skills beyond technical skilling. One of the most significant changes made by educational research has been to redefine the goals of learning. Decades ago, before the development of contemporary learning theories, schools emphasized developing core skills such as reading and memorizing information such as dates and facts in a history class. The implicit assumption was that this level of learning was sufficient for students to write reports, solve problems, and produce other sophisticated applications of literacy. However, while many students could demonstrate ability at, for instance, providing the correct solution for a specific type of word problem, educational researchers found that students rarely understood what they had learned, nor could they easily apply their skills and strategies to new contexts (Clement, 1982). The students knew

their lessons by rote and adapted to succeed at their instructor's tests, but they had a superficial understanding of the material. Today however, educational models and expectations have evolved, digital technology is often relegated to this type of learning.

While skills and facts remain important to learn, the goal of education today has been restated: to provide students with a foundation of deep learning and the intellectual tools to ask and address meaningful questions. (Bransford, Brown, and Cocking, 1999) In contrast to superficial learning of facts and procedures, deep learning entails knowledge of the underlying principles, domain structure, and strategies to activate skills and knowledge and apply them flexibly in a variety of conditions – particularly conditions which are different from the ones where learning originally occurred, such as the translation of design thinking from an academic to professional context. Deep learning is what most instructors would recognize as productive and transferable learning, yet few courses actually achieve. Architectural studios are examples of a deep learning environment.

In contrast to architectural studios, the current state of digital design instruction in architecture tends to follow an educational model which does not support deep learning. Presently, much of what students learn is by rote: sequences of commands and procedures intended to produce reliable results. While students can operate software and other tools with what appears to be great fluency, the vast majority do not have a deep understanding of computing or digital media principles (Sense, 2014). As a result, their work tends to be inefficient and derivative. Like the school teachers in the earlier example, digital design instructors emphasize core skills for using digital tools and then expect students to apply them towards design projects. This is the reason a learning gap exists. First, students do not learn the tools with significant guidance to develop depth and rigour; second, they are not taught explicit strategies for applying digital methods to design tasks. Students often fail to develop an understanding of digital design methods because the pedagogy is not aligned with the goal of deep learning. This leads to a frequently cited criticism of digital design: work which is repetitive or derivative because students are grappling with technology rather than controlling it. The technology does not make it this way – it is how it is used.

This is assuming such a goal is recognized in the first place. Learning digital tools is often seen – by students and faculty alike – as mere technical skilling rather than a way of thinking about design. Professional architectural accreditation (NAAB) in American schools uses a set of learning criteria which specify Ability and Understanding (NAAB, 2014). However, this set of criteria does not address digital design with any specificity. There is no agreement upon the value or content of a digital design education, and so student abilities can vary widely from school to school, and within academic units. Students are less inclined to develop a thorough knowledge of digital design because it is not universally considered a meaningful intellectual and creative pursuit. This not only hinders progress within the discipline, but, in practical terms, it affects the profession. Failure to recognize the principles of digital tools and structures of problems they address makes it more difficult for students to learn and retrain themselves in response to changing technology.

The educational model of the design studio is unique in its approach because it has many elements which contribute to the production of deep learning, such as opportunities for synthetic learning, active learning, complex problem solving, and self-reflection and critique. This is precisely the kind of approach that would benefit digital design education. Unfortunately, the architectural design studio is often seen as one type of learning, while digital design, which is thought of as mere technology, is seen as another. This disconnection is due to a misunderstanding about digital design due to a lack of clearly-defined and shared pedagogical goals. The present situation in education has come about because the implied goal of digital design education is mere tool operation (which does not require deep learning) when the expected outcome should be increased agency and sophistication of design ability. One way to address the problem of pedagogical misalignment is to develop learning objectives for digital design. Learning objectives have the benefit of being a structured, well-understood, and research-based approach to curricular development. This method informs clarity and represents an explicit way to connect the goal of deep learning with pedagogical execution.

BLOOM'S TAXONOMY

A useful tool for developing better learning objectives is Bloom's taxonomy. The taxonomy is a hierarchical framework intended to help instructors coordinate their planning and assessment using a common language (Krathwhol, 2002). It represents the process of learning from acquiring simpler to more sophisticated thinking skills. The general idea of Bloom's taxonomy is that lower levels of cognition support higher levels. For instance, one must understand the difference between different methods of constructing a surface (comprehending) before choosing which surface to use (applying).

In its revised form, Bloom's taxonomy lists six levels of cognitive processes:

1. **Knowing:** memorization and factual recall
2. **Comprehending:** understanding the meaning of facts and information
3. **Applying:** selection and correct use of facts, rules, or ideas
4. **Analyzing:** breaking down information into component parts
5. **Evaluating:** judging or forming an opinion about the information
6. **Creating:** combination of facts, ideas, or information to make a new whole

A more recent addition to the discussion of the taxonomy is the inclusion of types of knowledge. Anderson and Krathwohl addressed criticisms of the taxonomy by recognizing that not all knowledge is equal in complexity and that knowledge tends to be developed from concrete (facts and concepts) to abstract (procedural) and finally to knowledge of one's own cognition (metacognitive) (Anderson and Krathwohl, 2001). In concert with cognitive processes, the knowledge dimension of the revised taxonomy enables a more nuanced discussion of learning objectives. For instance, under the newer version, the taxonomy does not progress and stop with creating, but also includes thinking about one's learning progress and how one creates.

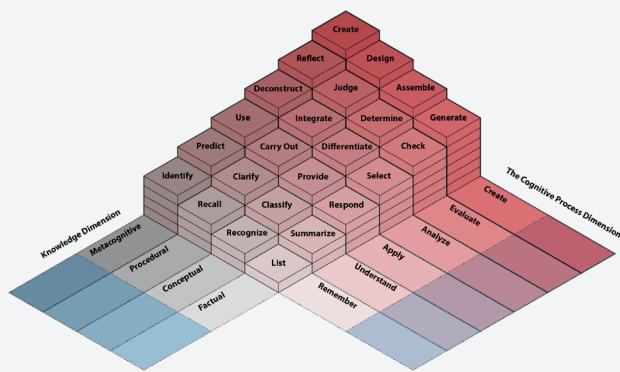
Bloom's taxonomy has been criticized because it does not represent the complex and interconnected nature of cognition (Furst, 1981), but the taxonomy was never conceived of as a model or theory. Nor is it a prescription for every course to follow. One could design a course with at least one learning objective at each level. Depending

upon the skills required, some levels may need additional objectives. Students with different abilities may be able to begin learning at higher levels. The value of the taxonomy is less that it represents exactly how learning works or that it tells instructors how to teach, but rather in how it helps to organize and align pedagogical thinking. Educational frameworks like Bloom's taxonomy are not in common use in architectural education. The reason for this is unclear but may derive from a disciplinary resistance to self-articulation. However, for those developing or revising architectural curricula, having access to a set of learning objectives that uses the taxonomy can enable a dialog within the discipline, with other disciplines and educational researchers.

Bloom's taxonomy helps support the goal of developing deep understanding in digital design instruction. One way it accomplishes this is by establishing the basic cognitive processes involved in learning to design thoughtfully. To see all of these steps organized and consider them with respect to digital design is to shed light on what is often an opaque practice. The taxonomy makes it clear that one does not just use or not use various tools, but one must understand them, choose from them, and evaluate those choices as part of a design process. In this manner, an advantage of learning objectives developed through Bloom's taxonomy is that they can elevate student outcomes towards higher-order thinking (Biggs, 1999). For example, without the proper outcomes articulated, a student might submit a design, but by merely applying a procedure. Bloom's taxonomy makes it clear that creation depends as much on understanding one's decisions (the "why") as knowing the correct commands (the "how" – which is often students' focus). For teachers and students alike, Bloom's taxonomy helps clarify that the goal of digital design instruction is not only to learn how to use digital tools, but to apply them towards better designs and more sophisticated design thinking.

With regards to teaching methodology, the clarity of learning objectives derived from Bloom's taxonomy can help motivate qualities of student performance which are often lacking in digital design courses, such as innovative solutions and well-crafted, thoughtful representation. As mentioned in the previous section, many learning objectives are not specific enough, sufficiently measurable, or targeted to student's learning level. Bloom's taxonomy can help ensure that students are practicing the skills that they should be learning in their activities and at an appropriate level of cognition. This enables the pedagogical gap between learning digital methods and creating designs to be filled with deliberate (or mindful) practice.

Deliberate practice is a recognized process through which individuals train themselves to high levels of performance. Research has shown that learning of complex skills is most effective when students engage with tasks that are appropriately challenging, with clear performance goals and feedback, and sufficiently frequent opportunities for practice (Ericsson, Krampe, and Tesch-Römer, 1993). The difference between merely making and deliberate practice is that a student monitors their progress towards a specific goal and changes their performance in response to feedback. The student continues to do so while increasing the challenge of the activity to further improve. Learning objectives assist students in deliberate practice by creating specific and appropriate performance goals which they can use to monitor their progress. This guidance directly supports the development of abilities on the highest (metacognitive)



| Bloom's Taxonomy 1956 | Bloom's Modified Taxonomy 2001 | Bloom's Digital Taxonomy 2007 | Associated Skills | Digital Skills | Communication Spectrum |
|-----------------------|--------------------------------|-------------------------------|--|--|--|
| Evaluation | Creating | Creating | Designing, constructing, Planning, producing, inventing, devising, making | Designing, programming, filming, animating, blogging, mixing, re-mixing, vlogging, videocasting, podcasting, directing | Collaborating Moderating Negotiating |
| Synthesis | Evaluating | Evaluating | Checking, hypothesizing, critiquing, experimenting, judging, testing, detecting, monitoring | Blog commenting, reviewing, posting, moderation, collaborating, reflecting, testing | Debating Commenting Video Conferencing |
| Analysis | Analyzing | Conceptualizing | Comparing, organizing, deconstructing, attributing, outlining, finding, structuring, integrating | Hacking, mashing, linking, validating, reverse engineering, cracking | Reviewing Quadranting Commenting |
| Application | Applying | Applying | Implementing, carrying out, using, executing | Running, loading, playing, operating, uploading, sharing with group, editing | Posting Networking Contributing |
| Comprehension | Understanding | Connecting | Interpreting, summarizing, inferring, paraphrasing, classifying, comparing, explaining, exemplifying | Boolean searches, tweeting, categorizing, tagging, commenting, annotating, subscribing | Chatting E-mailing Tweeting |
| Knowledge | Remembering | Doing | Recognizing, listing, describing, identifying, retrieving, naming, locating, finding | Bullet pointing, highlighting, bookmarking, group networking, shared bookmarking, searching | Testing Instant Messaging |

▲ Figure 1 Bloom's taxonomy was first introduced in 1956 and since then has seen widespread use in instructional design. A revised version was issued in 2001, which changed the levels from nouns into active verbs, added the knowledge dimension, and placed creation (synthesis) at the top of the hierarchy of cognitive process [Krothwohl , 2002]. More recently, Churches created a "digital" version of Bloom's taxonomy that updates many its application to computing activities [2004].

level of the taxonomy, which are crucial for sophisticated work and achieving transfer of skills and knowledge to other domains [Perkins and Salomon, 1992]. Thus, the notion of deliberate practice stands in contrast to the disengaged ways that many students learn and use digital tools, which is often oriented towards production for its own sake rather than for quality or thoughtfulness. Introducing deliberate practice is one way for schools to motivate deep understanding and to bring craft back into discussions about digital representation.

LEARNING OBJECTIVES FOR DIGITAL DESIGN

The idea of a learning objective is straightforward, but often misunderstood and misapplied. A learning objective is a specific statement which describes what a student will know [knowledge] be able to do [skills] as a result of engaging in a learning activity. A learning objective must have three parts: a measurable verb associated with the intended cognitive process, the necessary condition (if any) under which the performance is to occur, and the criteria for measuring acceptable performance (this is often implied). A simplistic example of a learning objective that fits this pattern is: "Given a set of contours the student will be able to generate a topographic model." The

condition is having a set of contours and the implied measurement is an acceptable model. Learning objectives are focused solely on student outcomes and do not specify methods or other expectations for the teacher. They are not an attempt to create uniform classroom procedures or hinder instructor creativity through standardization. The teacher has flexibility in their approach, so long as the performance criteria are met. Learning objectives are useful because they help instructors with course planning and the creation of content. Furthermore, the explicitness of properly-constructed learning objectives establishes a basis for student assessment as well as the evaluation of teaching and curricula (Anderson, 2002). A primary challenge of digital architecture evaluation is the lack of criteria and therefore a lack of agreed-upon traits for which to evaluate whether digitally produced code, drawings or images are successful.

In this manner, learning objectives support better learning and provide a common framework for schools to organize their efforts at improving education. For this reason, many universities have standardized their syllabus policies to address learning objectives [see (Vanderbilt, 2016) and (Carnegie Mellon, 2016) for example]. The use of learning objectives may seem obvious or unnecessary if one is only considering their use in one's own syllabi, but in terms of disciplinary alignment, digital design instruction could benefit from the additional clarity offered.

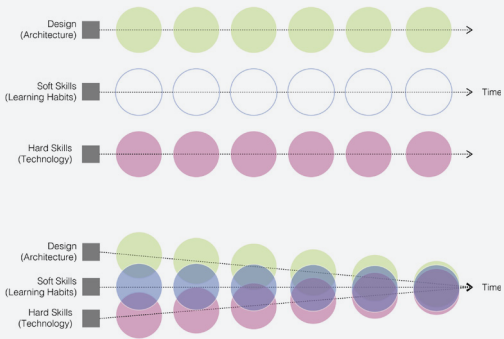
The real issue is not that learning objectives do not exist for digital design courses, but rather that they are not often used correctly, in response to the findings of educational research. First, many stated learning objectives do not take into account the learning process for developing complex skills and thinking. As mentioned earlier, traditional digital design pedagogy tends to emphasize learning through design tasks. The tacit learning objective of most activities, ostensibly, is to design something via digital methods. However, this does not acknowledge the steps involved to prepare students for design, such as learning about the tools, practicing methods, comparing and selecting methods, etc. These skills and knowledge are implied by the goal of designing, but by not stating this explicitly, the instructor might neglect teaching and assessing the constituent skills and knowledge that students need, but might not manage to learn on their own.

When developing learning objectives, it is important for digital design instructors to acknowledge how learning occurs as a developmental process. Creativity and autonomy, abilities exercised in design work, are higher order thinking skills. Higher order thinking is dependent upon requisite technical skills and other cognitive resources (Weiss, 2003). As such, these activities may not be beneficial learning experiences for beginner and intermediate students. Research shows the importance of matching learning objectives to student level (Klahr and Nigram, 2004). Novices benefit from direct guidance in basic skills and knowledge, while objectives for advanced students should emphasize synthesis and independence.

Second, many learning objectives for digital design instruction conflate activities and goals with learning outcomes. A goal is a statement of the overall intended outcome of a learning activity or course. Learning objectives are specific achievements which contribute to the goal (Ferguson, 1998). For example, a course description that says "students will be exposed to digital fabrication technologies" has presented



▲ **Figure 2** Knowing how to operate a smartphone does not necessarily make one an effective computer user.



▲ **Figure 3** The top diagram demonstrates a curriculum where design (architecture) and hard skills (technology) are typically taught in parallel. The bottom diagram demonstrates that soft skills (learning habits) create the bridge between design (architecture) and hard skills (technology). Over time these skills become mutually supportive.

a goal, but not stated a specific, measurable outcome. Likewise, a statement such as “students will fabricate a small-scale physical model” describes an activity, but does not provide enough information to discern what students are supposed to learn from the activity. A learning objective that addresses these issues would be: “students will use GIS data to generate a small-scale physical model using appropriate digital fabrication techniques.” This objective presents a condition [GIS data], an outcome [the model], and assessment criteria [are the techniques appropriate? / is the model is correct?]. Understanding the learning objective helps define the cognitive skill level of the activity and the appropriate assessment. For instance, if the objective was to learn about computing concepts, issuing a quiz with questions about procedures would not be a helpful measurement. To facilitate effective instruction, goals, activities, and learning objectives must be aligned with one another.

Last, many learning objectives as presented do not support a means of formative assessment. Most courses only assign grades for projects, which are typically creative or design work. Again, these are higher order thinking skills and may not be appropriate to assess from novices. Grading project submissions does not give the instructor or the student much opportunity to remediate skills or knowledge that were misunderstood or not acquired. Moreover, feedback on a design artifact may not help instructors and students achieve the goal of deep understanding because it makes conceptual and procedural knowledge indistinguishable from the outcome. Studies have shown that ability to perform procedural tasks does not mean students are able to explain what they are doing or why [Schoenfeld, 1985]. This is not to say that instructors should never grade projects. This is appropriate when the intent is to assess creative work and problem solving, particularly from an advanced class. Learning objectives should measure the correct student outcomes for the level of the student and in a manner that allows students to respond with changes in their performance.

SOFT SKILLS AND FOSTERING LEARNING HABITS

The development of rigorous learning objectives is the first part of creating a learning environment for digital design. The second proposal of this paper is to cultivate a

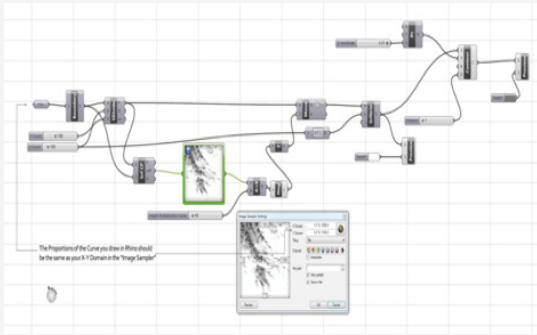
set of complementary “soft” skills which are currently missing in most digital design instruction. Computer use in architecture is often discussed and taught as a series of technical or “hard (as in absolute)” skills. In contrast, “soft” skills are related to emotional intelligence, attitudes, habits, and interpersonal relationships. An example of a soft skill is resourcefulness: being inclined and able to find alternate solutions to a problem, rather than giving up or deferring responsibility. In this manner, soft skills influence the ways that an individual applies technical skills to achieve goals, such as a design. Learning soft skills has been related to improved employment outlook and better job performance (Andrews and Higson, 2008; Nealy, 2005). Professions such as business and information services have cited employees’ lack of soft skills as one of the primary reasons why projects fail (Bancino and Zevalkink, 2007). Thus, for students, developing soft skills is equally as important, if not more important, than learning technical skills. This is because soft skills can be reapplied to changing technology, whereas hard skills may fall away as technology changes.

The influential Boyer report on architectural education concluded that: “[A]rchitectural education is really about fostering the learning habits needed for the discovery, integration, application, and sharing of knowledge over a lifetime” (Boyer, 1996). Soft skills are the learning habits Boyer references and as such must be taught rather assumed to be pre-existing skills. This also extends to those soft skills which relate to digital design in architecture. Hereafter, ‘digital tools’ refers to software programs, computing devices such as laptops, tablets, etc., fabrication systems (laser cutters, 3d printers, CNC machines, etc.), robots, embedded systems, and anything else that involves computers.

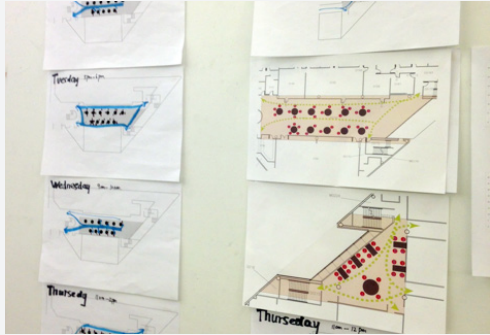
Architectural education must recognize that university students are not comprehensively or consistently trained in digital technologies when they arrive on campus. This is exacerbated when less privileged students are potentially less digitally skilled than students from economically privileged backgrounds. By not addressing these inequalities, institutions such as architecture schools are perpetuating disparities through education.

TRADITIONAL VS. DIGITAL SOFT SKILLS

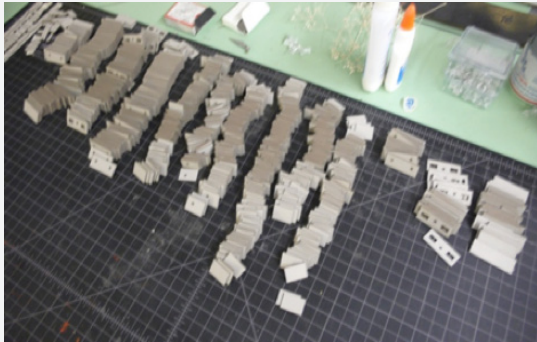
The type of soft skills described in this paper are not entirely the same as soft skills introduced in the previous section. While traditional soft skills such as conscientiousness and empathy are helpful for architects, digital soft skills have a different purpose and apply specifically to the tools and processes used in digital design. Digital soft skills, such as asking clear questions, estimation, and planning skills, enable effective collaboration with other people while using digital tools and promoting effective workflows for collections of digital tools. Digital soft skills support students as they are learning digital design and, later, help students apply technical skills successfully and with sophistication and to adapt to a rapidly changing technologic landscape. Digital soft skills also differ from traditional soft skills because they take into account the particular challenges of computing and digital machinery. The special attributes of digital tools that make them powerful, such as symbolic logic, abstraction, and automation, can invite cognitive biases when designers operate those tools simplistically, at face-value (i.e. using a computer like a cell phone, a pencil, or a typewriter). Humans must adapt their thinking, expectations, and habits, as their



▲ Figure 4 Example of a downloaded Grasshopper definition. Working digitally demands questions of authorship and intellectual property be discussed with students.



▲ Figure 5 Example of a response to a large print which failed. Soft skills encourage students to anticipate such failures and to develop alternatives, such as printing on smaller paper, creating analog versions, and using a projector.



▲ Figure 6 Example of a time management and workflow issue common in digital production. It must be reiterated that the computer is not automatic nor is digital production in and of itself ‘fast.’ A tedious laser file will become a tedious model to assemble.



▲ Figure 7 Example of a back up protocol. Soft skills enable students to feel confident that computers will fail and that they are empowered to seek alternatives.

natural inclinations can interfere with working effectively with digital tools (Sheil, 1983). Even those who work with digital tools frequently need to learn digital soft skills, as they may have developed bad habits and misconceptions over time. Merely using digital tools is not enough to cultivate mindfulness of the medium and one’s responses to it.

To cite an example: digital tools are often “black boxes” with complex layers of interrelated procedures that make it difficult for users to be aware of what they are doing and how their software operates. Users expect simple cause-and-effect relationships between their operations and the results on a screen, when the reality is that many “hidden” processes are at work and can affect the outcome of an interaction (Blackwell, 2002). This is also one reason why computers are not always dependable and why they tend to break down in obscure and obtuse ways. Working responsibly with digital tools requires a certain level of comfort and responsiveness with an opaque tool. Students who lack the digital soft skills to understand and respond to this condition often have a poor attitude when faced with computer problems and may spend their time in unproductive ways trying to “hack” solutions to technical

problems (Pea, 1987). This affects not only the quality of their final designs, but their outlook on technology in general. Digital soft skills are similar to traditional soft skills in the way they affect how students apply technical skills. They are the bridge across the gap that often exists between design skills and technical (hard) skills like digital methodologies. Unfortunately, very little time, if any, is given in architectural curricula to the explicit cultivation of digital soft skills.

SAMPLES OF DIGITAL SOFT SKILLS

The following list is a representative sample of digital soft skills which could be taught in an architectural curriculum, organized according to four primary headings.

Communications Skills

Communicating clearly with others is a critical set of soft skills for architects, particularly when using digital tools. For instance, many students have never been explicitly taught how to ask a question via email: to provide necessary information and files upfront, anticipate follow-up questions, and to communicate their expectations for resolution. This is important not only professionally, but especially when trying to learn or fix something like a new piece of software.

Collaboration - The ability to work with others digitally, particularly at a distance. One aspect of this is organizing files and sharing them across computing platforms and software versions.

Authorship - This is the ability to understand digital intellectual property and to distinguish between resourcefulness and plagiarism. This notion of authorship becomes increasingly important when the line between programmer and designer is blurred by the use of digital tools. Of particular note is the downloading of code or Grasshopper definitions which are then deployed as design generators.

Support - Architects should be able to seek, locate, and pursue support for software and technical issues, many of which might exceed the abilities of the instructor or the support offered by an academic institution. These skills include asking fellow students, contacting the software maker directly, and using the Internet as a resource.

Adaptability

Adaptability is resiliency in response to imperfect tools and a field constantly in change. Digital designers should work with the understanding that failures are to be expected, while being empowered to seek alternatives. They must also update their skills and abilities often while remaining critical users of technology.

Autodidacticism - The ability and inclination to teach oneself (quickly) is a valuable skill for designers. This includes planning and scheduling regular time to learn and a recognition of common concepts and methods shared between tools, which can make learning more efficient.

Conversion - An effective strategy for error recovery is knowing how to share data several between types of files and programs. It is important to also note that many computer programs are able to convert various file formats and

often have similar procedures.

Time Management

Digital design projects in architecture are often complex, involving many different programs and machines, as well as human team members. Some of these elements can be hands-off (such as rendering) or very hands-on (supervising CNC fabrication). Part of completing them successfully is knowing the workflows involved and having a sense of their coordination and time requirements.

Estimation - There is a common misconception that technology makes design faster and easier. It takes experience and skill to determine the full amount of time needed to complete a digital task or processes (e.g. milling, printing, rendering).

Sourcing - The ability to identify the most effective tool and process for the development of the idea and in relation to the time available for production. This requires understanding the different elements of digital production such as the difference between a raster and a vector.

Preparation - Plan for contingencies and alternatives. Assume some things will inevitably not go as expected and know the options available.

Scheduling - Develop internal deadlines, realistic calendars, and skills for planning and implementing a multi-step process. For instance: development of a digital file for fabrication, then fabrication, then post-production.

Digital hygiene

Digital hygiene refers to the good habits of caring for equipment, computer hardware and software as well as preventing and recovering from errors.

Organization - Maintain files in a structure which is both navigable and searchable by users.

Backups - Create a backup routine that is an embedded part of the digital process (cloud, physical media, & storage). This also includes knowledge and use of software auto-backup and recovery. Keep at least one physical backup off-site.

Clean-up - Regularly sort, store, and purge project files to manage storage and make important files easier to locate.

TEACHING DIGITAL SOFT SKILLS

Many of the examples listed under soft skills can be classified as character or personality traits. Successful students may already practice soft skills and therefore it is often assumed that these are character traits rather than teachable attributes. One might wonder, given the age of many college students, if such habits can be changed. However, the very notion of “soft skills” implies that these behaviors and habits can be taught to students. There is evidence to support the idea that, with training, young adult students can learn new traits and learning strategies (Perkins, 1989).

Another common argument is that soft skills are best learned in the workplace. While the workplace presents an authentic context, it does not offer the same opportunities for focused learning as design school. Moreover, one of the reasons for learning soft

skills is to make one more competitive in finding employment. Students should have a sense of how these skills translate into practice before they enter the market.

How can schools teach digital soft skills? Merely lecturing to students about them is not an effective strategy. While lectures can be helpful for delivering information or persuading an audience, changing and developing habits requires more engagement. The method of training varies depending upon the attribute and the audience, however, generally-speaking, habits of learning can be developed through a process of investment and practice.

Supporting a new habit which a student does not create themselves requires helping them understand its meaningfulness. It can be easy to dismiss soft skills out of hand because they might seem to be obvious or less interesting than learning technical skills. For this reason, it is important for the instructor to communicate why new strategies and habits are helpful (McCombs, 1996). Investment begins by identifying the soft skills in question and explaining to students the value of the skills within design and production workflows. To be most effective, those values should be immediate and goal-oriented. Although it is true that developing soft skills can help a student get a job in the future, explaining to a student (for example) that organizing their files saves them time and reduces errors on their current project is less abstract and applies to their current situation. Helping students understand the gaps in their present abilities and how learning soft skills can help close those gaps is the first step toward effective habituation.

To be most effective, teaching soft skills should be integrated with hard skills teaching and preferably in the context of a project (White and Frederickson, 1998). It is not necessary to revamp an entire course around soft skills. An instructor can introduce them where they naturally occur within design and production processes. For example using an error that students commonly encounter to introduce search, problem-solving, and communications skills. Relevant material like this helps focus student attention while a legitimate context helps them retain and access what they have learned later.

Demonstrations can be more effective when they are supported by teaching materials that help organize knowledge for students (Bransford, Brown, and Cocking, 1999). A simple check-list, for example, can help students remember how to organize a digital group project. Once students have mastered the soft skills involved, the student will not need the scaffolding provided by the list. However, if the student makes a mistake or needs to refresh their learning later, the list provides a useful reference and a prompt for activating digital soft skills. Externalizing implicit practices and helping students focus on relevant information and methods improves the effectiveness of soft skills teaching.

Delivering soft skills in class benefits from a coaching approach. Because the goal is to change student attitudes over time, rather than delivering information or procedures, a “one and done” demonstration is not an appropriate teaching style (Mistrell, 1989) (Bransford and Stein, 1984). With coaching, the instructor discusses the advantages of a skill (creating investment), then models the behavior while explaining to the student what they are doing and why. This last step is important because students

need to understand when to apply a skill as much as they need to know the technical operations involved (Scardamalia, Bereiter, and Steinbach, 1984) (Simon, 1978).

Next, students demonstrate the skill and receive feedback from the instructor on their performance. This is followed by more practice and feedback over time and in concert with other skills to approximate holistic design activities. The goal of coaching is to cultivate not just practice but deliberate practice over time – making the student aware of their own actions and motivating retention and refinement (Ericsson, Krampe, and Clemens, 1993). This creates deep and lasting learning.

Adopting a coaching style of instruction requires a change in how students are graded and given other feedback. Most assessment in studios and seminars is summative, meaning it measures the final outcome of a student's work. This is suboptimal for shaping behaviors, as it does not measure the process sufficiently and is often too late to influence a student's soft skills. Formative assessment techniques, which encourage personal reflection, timely feedback, and student response are useful support for the "coaching" (Vye et al., 1998). To supplement these techniques, instructors should not only observe student behaviors but review digital files, as well. Many courses emphasize the final artifact and never look at the files involved. Reviewing files is critical so the instructor can observe attributes such as organization, efficiency, and other procedural nuances.

Lastly, in order to properly cultivate habits, soft skills should be reinforced in the studio and lab even when they are not being formally taught. Instructors should be mindful and consistent in their own habits, demonstrating modeled behaviors in their personal actions. For example, an instructor's demonstration files should be well-organized to set a good example for the students. Student interactions should also emphasize consistent behavior. If a student asks for help with a tool, for instance, the instructor should evaluate how the student asks questions and replay the scenario with them while making explicit the strategies involved. Learning should be embedded in the classroom experience. It must be a continuous practice, not merely an exercise.

DISCUSSION

The challenge of making claims about design pedagogy interventions, like soft skills, is proving their effectiveness. In educational research the difficulties of empirical measurement in traditional subjects like math and reading are well-known (Black and Wiliam, 1998; Shepard, 2000), but the challenges of demonstrating the impact of an intervention upon design outcomes – which are not easily measured or quantified – make this task even more burdensome and its conclusions unreliable. As such, there is no accepted model for proving the effectiveness of design pedagogy. What is more important and perhaps easier to 'prove' is that well-articulated digital soft skills create a framework and a platform where technology can be used expansively and in unique ways rather than reductively and repetitively. The value of digital soft skills is to suggest a replicable model which remains relevant and useful for students as technology changes, improves, and adapts.

With regards to learning objectives, their value is not what they add to a syllabus, but rather how they prompt a larger conversation about educational and professional

values and standards. Creating learning objectives for digital design in architecture exposes many implicit assumptions about what faculty believe about learning and the role of computing in the studio. At the same time, discussing learning objectives is a provocation towards architecture schools to consider digital design as more than merely learning to operate tools and software (activities which are not themselves valid learning objectives) and to instead connect these practices to design thinking and the development of architectural designs.

Bloom's taxonomy assists in framing a more constructive discussion about learning to design digitally by offering a structure of cognitive accomplishments for students. This helps re-align architectural educators away from frameworks derived from folk pedagogy and towards established theories and research into educational psychology and learning cognition. Instead of teaching and learning digital skills and knowledge through a hierarchy of the tool's features or increasing complexity, Bloom's taxonomy foregrounds processes of remembering, thinking, and judgement. These objectives are more closely aligned with deeper understanding and integrative mastery. This type of learning is precisely the antidote to the kind of superficial engagement one often finds in architecture schools that prompts negativity towards the use of computing in design.

The purpose of reflecting upon learning objectives for digital design in architecture is not to produce a definitive list of what students ought to learn. Learning objectives are written for specific curricula, student needs, and faculty interests. They are useful because they provide a clear definition of expected outcomes and which becomes a point of dialogue. In order to evaluate something, it first must be named. Through evaluation and discussion, a discipline develops. When Bloom created the learning taxonomy, this was the goal. Not to explain or lay claim to how students must learn, but to provide a shared structure so educators could compare their approaches. In a similar manner, creating and sharing learning objectives for digital design instruction can produce a more organized dialogue about how to align the use of digital tools with the core values of architectural education and the development of the discipline itself. The development of a more coherent set of evaluation criteria in digital education will increase the rigor of conversations about the future of digital design in architecture. Learning objectives are not only for evaluating one's students or teaching. They help departments and educators understand whether they are teaching the right things. The question should always be: "how does this improve design?"

CONCLUSION

While digital design skills are critical for 21st century designers, architectural education must also recognize and deliver more than technical proficiency. Working creatively and effectively with computers, digital fabrication machines, and other devices requires a new set of workflows and adaptations to academic and professional behaviours. Boyer's report makes it clear that one of the key values of an architectural education is developing learning habits. A present gap in student learning is that traditional learning habits have not been updated in response to changes in technology (Boyer, 1996). Learning objectives and soft skills for digital design can help to bridge these gaps.

Incorporating learning objectives and soft skills into existing digital instruction may require more work from both the instructor and the students, but the benefits are lasting. Becoming more aware of one's process and developing good digital habits pays off, no matter what software or tools one encounters. Ultimately, teaching learning objectives and soft-skills is about making students more independent and self-directed learners. With the rapid pace of technological change, students need to be comfortable with and capable of learning, relearning, and integrating new programs and tools throughout their career. For these reasons, learning objectives and soft skills can and should be implemented throughout digital design education.

Learning objects and soft skills support the goal of not only working well with technology, but together with other people in technologically-supported ways. Knowledge, abilities, attitudes, and habits not only shape one's process, but one's design goals and outcomes, as well. Soft-skills and learning objectives impact design and so they extend beyond pedagogical or semantic arguments. They should be of interest to anyone who values how technology supports good design.

REFERENCES

- Anderson, L.W., Krathwohl, D.R. and Bloom, B.S., 2001. A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Allyn & Bacon.
- Anderson, L.W., 2002. Curricular alignment: A re-examination. *Theory into practice*, 41(4), pp.255-260.
- Bancino, Randy, and Claire Zevalkink, 2002. "Soft Skills: The New Curriculum for Hard-Core Technical Professionals." *Tech-niques: Connecting Education and Careers* (J1) 82.5, pp. 20-22.
- Biggs, J., 1999. "What the student does: teaching for enhanced learning." *Higher education research & development*, 18(1), pp.57-75.
- Blackwell, A., 2002. "What is Programming?" 14th Workshop of the Psychology of Programming Interest Group.
- Boyer, Ernest L. and Lee D. Mitgang, 1996. *Building Community: A New Future for Architecture Education and Practice: A Special Report*. Jossey-Bass Inc. (Preface xvi)
- Bransford, John D., Ann L. Brown, and Rodney R. Cocking, 1999. *How people learn: Brain, mind, experience, and school*. National Academy Press.
- Bransford, John D., and Barry S. Stein, 1984. "The IDEAL problem solver."
- Bruner, J.S., 1996. *The Culture of Education*. Harvard University Press.
- Carnegie Mellon Eberly Center for Teaching Excellence and Educational Innovation, 2016. "Bloom's Taxonomy." <https://www.cmu.edu/teaching/designteach/design/bloomsTaxonomy.html> Accessed on January 10, 2016.
- Churches, A., 2009. "Bloom's digital taxonomy." <http://burtonslifelearning.pbworks.com/f/BloomDigitalTaxonomy2001.pdf> Accessed December, 30, 2015.
- Clement, J., 1982. "Students' preconceptions in introductory mechanics". *American Journal of Physics*, 50(1), pp.66-71.
- Dans, Enrique, 2014. "The Absurd and Unfounded Myth of the Digital Native." Jun 4, 2014 <https://medium.com/enrique-dans/the-absurd-and-unfounded-myth-of-the-digital-native-45d1ff397785#.t959mvxza> Accessed January 9, 2016
- Ericsson, K. Anders, Ralf T. Krampe, and Clemens Tesch-Römer, 1993. "The role of deliberate practice in the acquisition of expert performance." *Psychological review* 100.3, p. 363.
- Ferguson, L.M., 1998. "Writing Learning Objectives." *Journal for Nurses in Professional Development*, 14(2), pp. 87-94.
- Furst, E.J., 1981. "Bloom's taxonomy of educational objectives for the cognitive domain: Philosophical and educational issues." *Review of Educational Research*, 51(4), pp.441-453.

- Kieran, Stephen and James Timberlake, 2003. *Refabricating Architecture: How Manufacturing Methodologies Are Poised to Transform Building Construction*. McGraw-Hill Education.
- Klahr, D. and Nigam, M., 2004. "The equivalence of learning paths in early science instruction effects of direct instruction and discovery learning." *Psychological Science*, 15(10), pp.661-667.
- Krathwohl, D.R., 2002. "A revision of Bloom's taxonomy: An overview." *Theory into practice*, 41(4), pp.212-218.
- McCombs, Barbara L., 1986. "Alternative perspectives for motivation." *Developing engaged readers in school and home communities*, pp. 67-87.
- Mistrell, J., 1989. "Teaching Science for Understanding". pp129-149 in Resnick, Lauren B., and Leopold E. Klopfer. *Toward the Thinking Curriculum: Current Cognitive Research*. 1989 ASCD Yearbook. Association for Supervision and Curriculum Development.
- National Architecture Accreditation Board, 2014. "2014 Conditions for Accreditation." http://www.naab.org/accreditation/2014_Conditions. Accessed January 16, 2016.
- Pea, R.D., 1987. Logo programming and problem solving.
- Perkins, D.N. and Salomon, G., 1989. Are cognitive skills context-bound?. *Educational researcher*, 18(1), pp.16-25.
- Perkins, D.N. and Salomon, G., 1992. "Transfer of Learning." *International Encyclopedia of Education*, 2.
- Prensky, Marc., 2001. "Digital Natives, Digital Immigrants." *On the Horizon*. MCB University Press, Vol. 9 No. 5.
- Pallasmaa, J., 1996. *The eyes of the skin: architecture and the senses*. John Wiley & Sons.
- Raths, J., 2002. Improving instruction. *Theory into Practice*, 41(4), pp.233-237.
- Scardamalia, M., Bereiter, C. and Steinbach, R., 1984. "Teachability of reflective processes in written composition." *Cognitive Science*, 8(2), pp.173-190.
- Schoenfeld, A.H., 1985. *Mathematical Problem Solving*. Orlando, FL: Academic press.
- Simon, H.A., 1978. *Problem solving and education*. Carnegie-Mellon University, Department of Psychology.
- Senske, N. 2014. "Confronting the Challenges of Computational Design Instruction." *Computer Aided Architectural Design and Research in Asia (CAADRIA) Conference*, Kyoto, Japan, pp. 821-829.
- Sheil, B.A., 1983. "Coping with complexity." *Office Technology and People*, 1(4), pp.295-320.
- Weiss, R.E., 2003. "Designing problems to promote higher order thinking." *New Directions for Teaching and Learning*, 2003 (95), pp.25-31.
- White, B.Y. and Frederiksen, J.R., 1998. "Inquiry, modeling, and metacognition: Making science accessible to all students." *Cognition and instruction*, 16(1), pp.3-118.
- Vanderbilt University Center for Teaching, 2016. "Bloom's Taxonomy." <https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/> Accessed January 10, 2016.
- Vye, N.J., Schwartz, D.L., Bransford, J.D., Barron, B.J. and Zech, L., 1998. "SMART environments that support monitoring, reflection, and revision." *Metacognition in Educational Theory and Practice*, pp.305-347.

Material / tooling / prototyping: the production of full-scale models in architectural education

Evan Greenberg

Architectural Association, UK

ABSTRACT

This paper explores the use of the performative model in architectural education, specifically through a Design/Build learning method. It argues that the prototype, or the full-scale development of an operational model, is a valuable mechanism for students in gaining knowledge of material, fabrication and construction techniques through the act of making. By examining three case studies of Design/Build pavilions undertaken in the Emergent Technologies and Design Programme at the Architectural Association from 2012-2015, this paper aims to develop an approach to education where the final output is only a means to an end, but where learning originates from the process of production itself.

INTRODUCTION

The model in architecture has a long-standing yet ambiguous history. In *Tools for Ideas: Introduction to Architectural Design*, Christian Gainshirt (2007) suggests “the architectural model can be used for a large number of purposes, which makes it a highly effective, but also problematical design tool,” in that the model is used commonly as a representational tool although also has the capacity to operate performatively. With the innovation of computation and fabrication in architecture over the past twenty years or so, the potential of the model as a performative prototype has increased dramatically; leveraging this technology provides new opportunities via the act of production.

Through the investigation of three case studies of Design/Build projects undertaken by students in the Emergent Technologies and Design Master Programme at the Architectural Association School of Architecture from 2012 to 2015, this paper interrogates the full-scale model as a mechanism for architectural education. *Carbon Curve*, designed and built in 2012-2013 explores the development of a material technique capable of controlling curvature and structural stiffness through the application of a slotting pattern to plywood sheets. In *Fingers Crossed*, from 2013-2014, the study of fabrication tolerances provides an opportunity for the development of a pavilion that solely employs friction joints, avoiding the use of any metal connections. Finally, *The TWIST*, designed and built in 2014-2015, interrogates the numerous issues around designing a cantilevered geometry with a complex construction process.

In all three examples, it is the production of the prototype that provides opportunities for learning. While computational tools are employed in the initial design process, the use of physical models provides necessary information which can only be obtained through the act of making. Rather than using this 1:1 model as a way of communicating ideas of fully realised designs, the prototype instead acts as a method for testing material properties, fabrication strategies and construction techniques, all of which lead to the production of both novel structures and new knowledge. Contrary to traditional academic projects, where value can be assessed by examining the end product, or final design, the Design/Build projects presented here assign value to the design process itself, where the development of learning is only possible through a constant feedback loop of production and analysis.

While the fabrication of models is ubiquitous in all schools of architecture, the position that these models take is vastly different. The traditional model has often been used to represent or communicate an idea, operating in many ways as a metaphor for a design principle or intent. At the same time, in contemporary architecture education, the fabrication of models as prototypes has become commonplace, with the widespread implementation of facilities such as digital fabrication laboratories internationally. This shift has redefined the very understanding of building, as *“not just the implementation of represented conceptions, but rather seen as a process by which one discovers and explores”* (Hensel and Hermansen Cordua, 2015a). However, it seems as if prototyping, particularly at the large-scale, is often categorised under the heading of Design/Build. This classification is however misleading, in that not all Design/Build projects are alike. While most projects of this kind are designed and built by the same team, some are highly exploratory, while others aim to deliver an architectural project (building, structure or interior) in its more traditional definition. This distinction appears to be borne not from the physical artefact produced, however, but in the process of production itself. Hensel and Hermansen Cordua (2015b) further state *“studios in most schools of architecture are omitting crucial aspects of the architectural process, and in so doing reinforce the chasm between education, research and practice.”*

RESEARCH AS EDUCATION

Within those few schools of architecture where the integration of education, research and practice are paramount, the relationships between them play a crucial role in the definition of the endeavour itself. The Design/Build project in the Emergent Technologies and Design Master Programme at the Architectural Association School of Architecture (EmTech), defines this approach as founded in the *atelier* tradition of many architects such as Jean Prouvé and Charles and Ray Eames, where the production of the prototype is a design tool rather than a design itself. In the late 1930s, for example, Jean Prouvé began to test the design of light and deployable structures such as a tent and a hut. These initial constructions were developed within the production of the one-to-one, rather than describe a state of completion of the construction itself (Centre George Pompidou, 2009). It could be argued, then, that these experiments in deployable structures were in fact prototypes of Prouvé’s Tropical House, testing and idea of production (in this case, deployability) rather than the development of a specific method of production.

Within this structure of process and production, EmTech aims to gain knowledge around innovative strategies of material systems and fabrication logics through large-scale prototyping. While these explorations pursue the development of research as a contribution to the larger body of work within material production, it too focuses on the education of students through the research and design process itself, via prototyping. Prototyping thus becomes a mechanism by which students understand properties of materials and



▲ Figure 1 Students and staff testing the use of a jig while prototyping a high-curvature panel of Carbon Curve. Credit: AA Emergent Technologies and Design

fabrication processes, but also in collaborative work and the organisation of design workflows.

While EmTech has designed and built numerous large-scale projects since its inception in 2001, the development of its most recent Design/Build works, specifically from 2012-2015, have focused primarily on the investigation of a design intent, or the exploration of an idea, in the Prouvéan manner, rather than the construction of a specific typological artefact. In each of the three projects, beginning from a one-week design competition, organised as extracurricular and unassessed activities and ultimately undertaken by a subset of students from the EmTech studio over the course of approximately 9 months, a brief to design a pavilion was used as a generic vehicle to explore the stipulated design idea. This prescription allowed for the simplification of the problem at hand, providing the students with an opportunity to focus on learning through prototyping rather than allocating resources toward practical requirements of programme or environment (with the exception of structural performance). Interestingly, despite this omission, these architectural effects emerged unexpectedly through the process of prototyping design.

CASE STUDY 01: CARBON CURVE, 2013

The 2012-2013 cohort in the EmTech Programme were asked to design and build a continuous surface capable of producing differentiated effects through controlling the variable stiffness of a plywood composite material. The design competition produced two similar and complimentary design ideas; an integrated design method of appropriating cutting patterns onto plywood sheets derived from surface curvature analyses. The primary material technique had been previously developed during the programme's first studio module by a group of students exploring the design of a perforation pattern applied to sheets of plywood. This technique allowed the plywood to perform unperforated, as



▲ Figure 2 Early prototype of a portion of the catenary arch testing tolerances and friction connection between elements in Fingers Crossed. Credit: AA Emergent Technologies and Design.

a stiff board, or highly perforated, with a 50% reduction in overall material, and somewhat like a fabric. A secondary material technique was included where pre-impregnated carbon fibre tape was bonded to the curved plywood sheets in order to retain curvature and connect individual panels together, forming a continuous surface [Greenberg and Körner, 2013].

Developing this material approach within the context of a Design/Build project required extensive physical prototyping. While the effects of material manipulation had been previously understood, the students had no prior experience working with the carbon fibre tape. While materially, its properties were understood, the construction of a rigidified panel had not been tested previously and the assembly of these panels were not previously defined.

Therefore, a series of full-scale tests were required so that the students would be able to gain knowledge in the relationship between geometry, material properties, fabrication and construction.

After the development of numerous experiments joining two panels together, the students set out to build 50% of the total designed pavilion in Hooke Park, the Architectural Association's woodland campus. This opportunity allowed the students to test and develop the construction process at full-scale. After 6 days of fabrication and construction, 4 sections of the pavilion were successfully erected on-site. However, overnight, the pavilion collapsed due to large changes in humidity in the outdoor environment, as well as a lack of structural performance of the carbon fibre tape due to poor lamination and insufficient thickness. While the pavilion itself ultimately failed, the prototype was largely successful, in that the knowledge gained from this test would not be possible within any other context. While Finite Element Analysis was used to analyse the global geometry without any perforations, it could have also been used to predict some of the perforated surface behaviour prior to construction; however, the complexity of the surface patterning and resulting material performance required physical prototyping to understand its structural behaviour. Furthermore, the students gained a clear understanding of the construction process, learning through making, and also in the way that the structure failed through live interactions. Furthermore, prior to failure, the differential patterns generated produced emergent effects with regard to views to the forest as well as light and shadow patterns generated, which had not been designed for previously. The prototype therefore afforded the opportunity for students to learn the relationship between structural performance and spatial effects through the simple material technique of pattern application.

CASE STUDY 02: FINGERS CROSSED, 2014

Fingers Crossed was the Design/Build project developed by students in the 2013-2014 cohort within the Emergent Technologies and Design Programme. While this project was initiated as a collaboration with the Timber Research and Development Association (TRADA) and Arup as a quickly constructable pavilion designed for the London Design Festival 2014 and Timber Expo 2014, the Emergent Technologies and Design Programme approached it not as the finite delivery of a commissioned project, but as the exploration of an idea around demountability. In this regard, a material system was developed where all connections were made through friction joints, rather than through metal connections. Similar to Carbon Curve, the principal material technique came from a previous studio module, where students rigorously tested the friction capacity between two comb-shaped geometries. This material technique was developed further as the joinery solution in the design of two bending-active catenary forms made of plywood, held in place by waffle-jointed plywood footings [Greenberg, 2015].

Numerous initial material tests, studying material thickness, tooth width and length and gap width were conducted as tabletop experiments in order to gain an understanding of initial material behaviour. However, these tests rapidly required full-scale production. Through physical prototyping therefore, students were able to gain an understanding of the behaviour of friction forces. More importantly, though, students developed an understanding for the role of tolerances within the design process. Therefore, prototyping became the main mechanism for the procurement of fabrication expertise. By linking the performance of plywood through friction forces with the cutting capabilities provided by a 3-axis CNC mill, the students were able to gain knowledge on element and gap sizing to make construction possible. This process provided a contribution both to the wider research field but also to the personal proficiency of fabrication and construction methods.

CASE STUDY 03: THE TWIST, 2015

In 2014-2015, EmTech again partnered with TRADA in the delivery of a pavilion for Timber Expo 2015. As in previous design/build projects, The TWIST was developed as a response to a specific call for ideas rather than in the delivery of a finalised pavilion design. The TWIST was undertaken to explore the idea of exploiting bending and twisting behaviour noticeable in plywood sheets. The proposal originated as the design of a Möbius geometry, where straight plywood members, referred to as wings, met stiff curved members, called ribs, at variable locations along their lengths, causing them to twist. This twisting generated a second direction of curvature along the surface, resulting in a doubly-curved surface geometry.

This material performance was tested in principle through precise geometric models as well as through tabletop material experiments. When this technique was first tested as a one-to-one prototype at the AA's Hooke Park, however, major structural issues became apparent, thus validating the importance of the prototyping process. A stiff edge beam was introduced in order to provide structural rigidity. Through the development of this prototype, the structural system of The TWIST changed from one where the twisting wings would provide structural stiffness to a system of stiff frames created between ribs and edge beam. The wings, then, generated a surface that filled in these frames and tied these two elements together fully. Prototyping, in the case of The TWIST, was used as a mechanism not only to explore structural behaviour, but subsequently as a tool to develop detail design. All joints were designed through full-scale constructions, and the knowledge of the material system as a whole developed through a large body of research through prototyping.



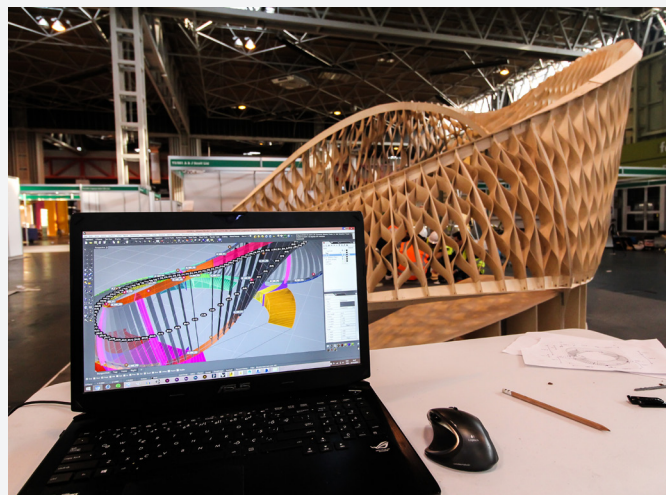
▲ ► Figures 3 & 4 Credit: AA Emergent Technologies and Design

Because the Möbius was intended to be used as an inhabitable pavilion, the geometry was designed to incorporate a cantilever, providing an entrance to the interior space. This cantilever, understood to be the most geometrically and structurally complex part of the pavilion was thus prototyped again for the AA's Projects Review 2015 in order to gain a better understanding of its performance. Through this process, a new edge connection design was developed, providing further stiffness to the cantilever. The TWIST was prototyped once more, and for the first time as a complete structure for Timber Expo 2015. Although the entire assembly process had not been explored previously, this prototype provided the opportunity to test this method on site. While issues of tolerance required real-time adjustments to the preconceived design, such as metal splicing in certain areas in order to maintain structural continuity, The TWIST was successfully prototyped in full.

DIGITAL AND MATERIAL COMPUTATION

In a number of contemporary architecture education models, digital computation is being used as a method to simulate, predict and design physical behaviour, sometimes in lieu of physical modelling. In all three examples explored above, however, the use of computation within the design process is employed in parallel to physical modelling. Digital computation was used in the generation of geometry, the integration of material properties within digital models, as well as in the simulation of physical behaviour through Finite Element Modelling. While these tools provide the potential for solutions to a number of issues faced, students can often struggle to find agency in the production of these digital models, where, as Barkow and Leibinger suggest (2012) “*the experience of material effect and haptic workability cannot be adequately simulated.*” This is particularly true in the understanding of scaling principles, connectivity issues, and in production of unexpected architectural effects. While simulation through digital computation is valuable, it fosters a disconnect between the tool used to experiment and the production of the experiment itself. Engaging in making through physical prototyping therefore requires that the student test strategies at full scale, where “*implications of detailing and construction emerged through the making of the prototypes with material mockups and test pieces acting as visual specifications,*” [Iwamoto and Scott, 2001].

This process facilitates the integration of the tool acting on a material, the material itself, as well as the technique used to physically make the prototype. Interestingly, the process of physical production also allows for unexpected events to occur. Often in computational simulation, unforeseen circumstances will be flagged as errors, and will not allow a procedure to run. While the accuracy provided by digital processes is preferred to the imprecisions which arise from human error in the physical world, discoveries can be made



▲ Figure 5 Credit: AA Emergent Technologies and Design

from the observation and evaluation of unplanned events, from structural innovations to spatial or visual findings.

The TWIST was first prototyped in Hooke Park, where the lack of stiffness in the edge beam resulted in structural failure (above left). Learning from this construction, the edge beam was stiffened for a subsequent prototype installed at Timber Expo 2015 (above right).

CONCLUSIONS

Prototyping in architectural education is not new, nor a necessarily novel approach to design. However, it is the attitude toward prototyping within the academic setting which is particularly innovative. Most Design/Build projects within academia aim to deliver a final product — a fully realised pavilion, interior, or in some cases, residential projects. The goals of the prototype within the three projects described here, however, focus on the knowledge gained through the development of the performative model itself. In this regard, there is no final design as such, only a logistical decision to end the research undertaken by the students. While this often leaves work unfinished, it opens new avenues of research for further exploration. Rather than deliver a conclusive, absolute product, the prototype enables students to gain knowledge in material, fabrication and structural technologies which facilitate larger research projects in greater depth. Thus, the prototype is not a means to an end but a mechanism for learning, providing students the opportunity to ask more appropriate questions in future endeavours.

Modelling through physical prototyping within this context thus develops specialisations amongst students, with some focusing on detailing and machining while others focus on procurement or structural analysis. This specificity allows for individuals or small groups to gain expertise in a focused area of research, but also requires each to communicate effectively within a collaborative environment. In *Designing Education*, John Nastasi (2012), Director of the Product-Architecture Lab at the Stevens Institute of Technology, writes about the changing nature of architecture as a discipline. He suggests that the design and construction industry will be highly collaborative, although most current models of architectural education are individual. This holds true for a great number of innovative contemporary practices, where collaboration exists not only between architects

working on the same project, but between those architects and their clients as well as with various consultants. With this in mind, EmTech Design/Build projects stress the importance of learning and executing within a team. While greater success is unequivocally achieved in the context of a collaborative environment, the structure itself provides students the opportunity to learn how to work within a group, by proffering a domain where multiple approaches must be tested and implemented, and where various cultures and values must be discussed and considered. The value of these interactions, while not formally assessed, contribute to the development of a rich body of knowledge that far surpasses the research benefit of the project itself.

Digital computational models were used to generate fabrication files, and as a guide for the physical prototyping at Timber Expo 2015. While the digital model was geometrically accurate, experience gained through numerous iterations of physical modelling allowed for control of inaccuracies due to material properties and tolerances.

REFERENCES

- Barkow, F., and Leibinger, R., 2012. Designing Assembly: How Tools Shape Materials that Constitute Space. In: Marble, S., ed., 2012. *Digital Workflows in Architecture: Design — Assembly — Industry*. Basel: Birkhauser. pp.94-107.
- Centre George Pompidou, 2009. Jean Prouvé: La Maison Tropicale/The Tropical House. Paris: Editions du Centre Pompidou.
- Gainshirt, C., 2007. *Tools for Ideas: Introduction to Architectural Design*. Translated from German by Michael Robinson. Basel: Birkhauser.
- Greenberg, E. 2015. Innovating the Joint: Connectivity Strategies for Higher Functionality in Architectural Design. In: Proceedings of the International Association of Shell and Spatial Structures (IASS) Symposium 2015, Amsterdam, Future Visions.
- Greenberg, E., and Körner, A., 2013. Subtractive Manufacturing for Variable-Stiffness Plywood Composite Structures. In: Setchi, R., Howlett, R.J., Naim, M., and Seinz, H., eds. 2014. *Sustainable Design and Manufacturing*. Shoreham-on-Sea: Future Technology Press. pp.50-66.
- Hensel, M., and Hermansen Cordua, C., 2015. Relating Perceptions of Constructions, Experimental and Local. In: Hensel, M. and Hermansen Cordua, C., eds., 2015. *Architectural Design Special Issue Constructions: An Experimental Approach to Intensely Local Architecture*. London: Wiley. pp.8-15.
- Hensel, M., and Hermansen Cordua, C., 2015b. Architecture by Latitude and Locality: The Scarcity and Creativity Studio. In: Hensel, M. and Hermansen Cordua, C., eds., 2015. *Architectural Design Special Issue Constructions: An Experimental Approach to Intensely Local Architecture*. London: Wiley. pp.48-57.
- Iwamoto, L. and Scott, C., 2001. Surface/Thickness Translated: Design-Build as a Vehicle. *Journal of Architectural Education*, 54(3), [online] pp.185-190. Available at: <<http://www.tandfonline.com/doi/pdf/10.1162/10464880152632505>> [Accessed 9 December 2015].



Crafting skins: Spatial and structural properties of laminated surfaces

Michael Budig, Singapore University of Technology and Design,
Singapore

Dishita Turakhia, Massachusetts Institute of Technology, USA

INTRODUCTION AND BACKGROUND

The explorations started with a curiosity in layering sheet material: a strictly additive assembly process that could potentially serve as a conceptual translation of 3-D printing into full-scale construction. Particularly wood panels are conventionally composed of several layers of thinner material, only to be cut again in the assembly process in order to be joined with other panels. The investigations in laminated surfaces are driven by the motivation to explore new functional and creative potentials, and to take advantage of the emerging lightweight and spatial components for the application as building skins. The structural performance can eliminate usual limitation in dimensions between load bearing members, and the spatial properties can provide for an integration of diverse functions into the skin.

Lamination is used to manufacture elements in multiple layers so that the composite resultant material achieves the desired balance of strength, stability, sound or thermal insulation, and appearance from a tailored combination of different materials. One of the most widely used laminates is plywood - a sheet material produced by gluing and pressing thin layers of wood veneer. The two aspects of the technique that govern the strength and stiffness of the end product are the number of veneer layers in the ply and the orientation of grains within each layer. The grains are orientated perpendicular or at an angle with respect to each other and layers are glued in odd numbers providing enhanced strength. Since the invention of plywood in the late eighteenth century, when the main applications were in shipping industry, the technology has expanded exponentially both in the fabrication techniques (with the recent progress in CAD/CAM tools) and in the diverse fields of applications. Other sheet materials such as metal sheets and composite materials have further varied and significant uses range still from shipping to aeronautical, automobile, and construction industries. A growing current interest in the process of lamination to develop unconventional materials is evident in the recent research, aiming for composite materials and recycled elements, such as heat pressure lamination technique to fabricate flat panels from recycled polyethylene-foil or shopping bags.

PREMISE

Undoubtedly, a vast scope and subsequent resourceful research exists on the application of flat panels in the computation of curved geometries. The same applies to lamination processes of new materials, mostly by applying heat and pressure, or welding techniques and chemical adhesives. However, there

are relatively limited precedents that explore the lamination process through geometric variation and morphological differentiation within its layers. For instance, plywood sheets have uniform and linear layers, with no variation in their thickness, or differentiation between the grades of core and surface veneer layers. There is no experimentation to develop non-uniform and non-linearly behaving hierarchical formation of layers with potentially more effective and efficient design solutions. This research positions itself in the premise of this unexplored design solution space and aims to formulate a system of design morphologies based on changing hierarchy of layers within the assemblies.

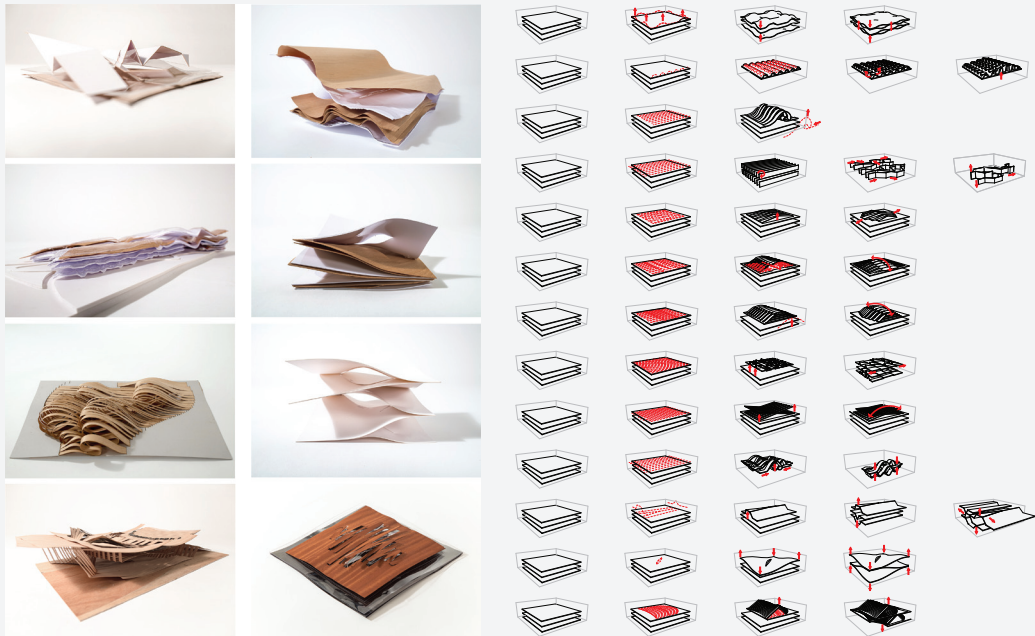
The research in its first stage studies the implications of incorporating hierarchy within layers – both structurally and formally. The second stage of investigation involves studying assemblies with non-planar and non-linear layers (for example, bending some or all veneers). The third stage studies assemblies having non-uniform layers with variation in orientation and/or thickness of layers. At the stage we coined the term dynamic hierarchies to describe a concept, where the role of the core and surface layers within lamination is interchangeable within the assembly. The fourth stage of the research experiments with applying this concept on multi-material combinations. The results are evaluated for the corresponding structural and formal advantages, shortcomings and variation in assembly properties.

STATE OF THE ART

While the concept of bending/curving layers in laminates is explored intelligently (both-for strengthened structure and innovative design) in recent timber products like Corruven or CoreLam, both taking advantage of a corrugated core layer and developed by Canadian companies. The latter was translated into furniture design objects by Benjamin Hubert. Some of the few other examples of design explorations that follow related concepts include the *Enignum II Table* by Joseph Walsh and the *Flow chair* by Cheng-Tsung Feng and Kao-Min Chen. Besides furniture design it is noteworthy to include preliminary approaches in fashion design. An outstanding example is the *A-POC* (A Piece of Cloth) project by Issey Miyake, which explores 3-dimensional attire formations by stitching and cutting through a continuous multilayered fabric. The project is particularly stimulating for its investigations in art and craftsmanship in addition to adopting the minimal waste approach (no figures due to copyright restrictions: please follow the provided links in the text for illustrations). This research on laminated surfaces goes beyond the uniformity of these products and adds another layer of complexity through the introduction of dynamic hierarchies in the layers. The unique advantage of creating 3-dimensional morphologies from 2-dimensional sheets, through least wastage makes the differentiated lamination of sheet materials significantly more optimised and an economical choice of construction material. Apart from sheet materials having the advantages of ease of transport and fabrication (through laser cutting/ water jet cutting using flat-bed) in comparison to other construction materials (such as solid timber, steel tubes, cables etc), these sheets also display bending and curving behaviour that can be used specifically to shape and strengthen the construction.

HYPOTHESIS

The goal of the research is to develop laminated sheet assemblies with enhanced structural performance (in addition to variation in characteristics like sound and heat insulation), by controlling the strength and stability of the composite result through modulation in bending curvature and joinery of layers. This proposal exceeds the existing conventional bending/curving and pressing techniques of construction and fabrication of laminates by incorporating design needs into the material system for producing efficient morphologies.



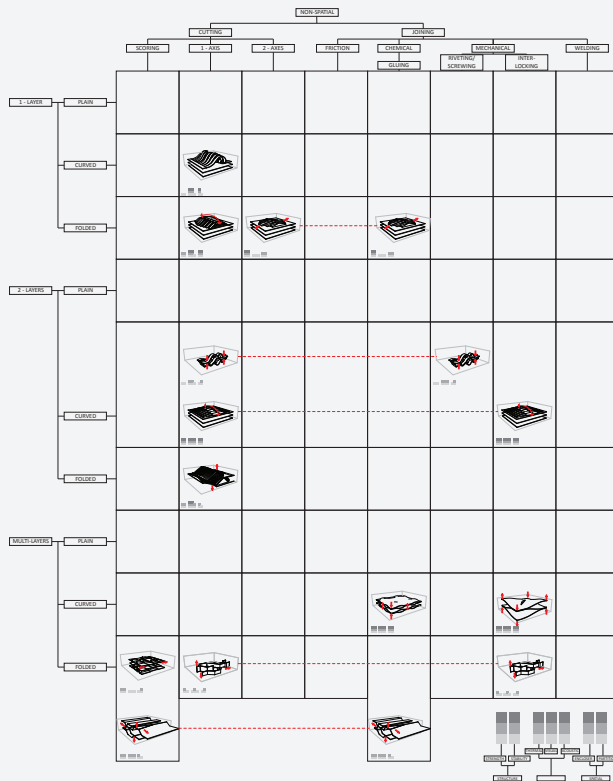
▲ Figure 1: The different lamination strategies in a design studio conducted at the Singapore University of technology and Design in 2015. The classification of the results displays different strategies like bending, folding, scoring, cutting, slicing and any combinations in order to achieve 3-dimensional surfaces; models (from top left to bottom right) by Lim Yan Ling Eileen, Amanda Yeo Qian Yu (2x), Toh Hui Ping Anna, Ao Chin Wen, Toh Hui Ping Anna, Xia Tian Summer, Melissa Lim Huay Hsien.

It explores new concepts of lamination such as dynamic hierarchical layering through initial formal experimentation as part of a design studio and then focused computational explorations and evaluation through physical experiments. The progressive design iterations focus on operative reciprocity between design and fabrication, in an investigative process of **crafting skins**.

METHODOLOGY

The investigations have been conducted in two parallel strands. The explorations of concurrent design research studios have been integrated in the research and offered a variety of speculative approaches that will be summarised here. The following chapters will focus on the empirical research into the lamination of sheet materials to design self-supportive structural surfaces with potentially varied architectural applications. The methodological aspects of design processes with the integration of physical experimentation and parametric tools, bridging the prevailing segregation of design, planning and building will be briefly outlined.

The primary motivation for this research is derived from (but is not limited to) timber production processes, and the manufacturing of plywood from layers of veneer. The research also investigates metal sheet materials like aluminium in the context of layering and lamination processes. A future expansion of the research will include composite materials, where the use of renewable and recyclable materials will be of particular interest. At the current stage the experiments highlight two specific aspects of lamination – structural performance and spatial characteristics; both are studied in the context of potential architectural applications.



▲ Figure 2: Categorisation of lamination strategies and evaluation of the specific structural and spatial properties.

PRELIMINARY EXPERIMENTS

Design Studio

The studio was titled *Building Skins*, provoking a critical view on the classical notion of segregating building functions into discreet systems, but instead reading it as an act of building [crafting] skins. It engaged the students to explore the concept of crafting surface morphologies by making shell-like components using materials like paper, wood veneer, plastic and metal sheets. Parametric design tools and generative algorithms were used to derive component based assemblies, which were then constructed using a mix of digital and manual fabrication processes like laser and water-jet cutting, vacuum forming and so on. The main objective of these studio explorations was to understand the material characteristics and to utilise them to design three-dimensional assemblies from two-dimensional sheets, through techniques of lamination and delamination. The series of variable and differentiated results produced were then analysed for their architectural characteristics (like spatial enclosures), strength vs stability variation and scalability limitations. The initially abstract and geometric explorations in the studio established the base and premise for translations into a repertoire of architectural articulation and formal experiments in the design studio, and for further material lamination in the academic research (Figure 1).

The 13 different design outcomes resulting from the studio project were compared and evaluated in three categories based on the number of layers, the method of transformation



▲ Figure 3: Example of cutting, bending an interlocking to achieve 3-dimensional surfaces; models by Clover Chen Yutong.

before or during lamination (or de-lamination) and finally the fabrication technique used for crafting the composite laminated sheet assembly (Figure 2).

Uni-layered, Bi-layered, Multi-layered Assemblies

While most of the projects started with uni-layered transformations to study the material behaviour using small-scale explorations, the design process eventually led to adding more layers (literally) of complexities to the assemblies. The number of layers plays a vital role not only in defining the strength of the assemblies, but also in determining the behavioural characteristics like bending/ folding etc. It was hence crucial to study the strategic correlation between the number of layers in the designs and formal explorations evolved in the projects.

Plain, Curved and Folded Formations

The transformation processes explored to deform the sheets could be categorised broadly into being planar, bent / curved and folded. By using combinations of these transformative processes, more intricately crafted techniques of pinching, twisting and interlocking were explored intelligently to develop fairly complex assembly systems. Although most of the choice of deformations (either bending or folding) essentially emerged from the material properties, joinery and material orientation also played a significant role in determining the global geometry (with anisotropic materials allowing folding and bending in only certain orientation).

Scoring, Cutting and Joining

In addition to deformation explored within the materials, the use of advanced fabrication technologies assisted in developing further enhanced complex systems. For example, scoring and cutting using laser-cutting or water-jet cutting displays how digital fabrication technology can evolve into developing a craft-life assembly system with structurally and spatially improved designs (Figure 3). Conversely, additive techniques as simple as gluing after folding algorithmically (by following specific set rules) can result in complex origami-like surfaces and patterns with potential of intricate architectural applications.

HIERARCHY OF LAYERS

The initial studio experiments facilitated in providing the proof of the strong relationship between the global form of the assemblies and the manner of connection between the sub-structural layers by establishing a hierarchy amongst the lamination layers. This essentially means that shape, strength and stability of one layer was governed by the manner, order



▲ Figure 4: Final studio model; model by Clover Chen Yutong.

and spacing of its connection to the subsequent layers. It was hence essential to study these formal implications emerging from controlling and varying the parameters in these mixed-hierarchical laminated sheet structures.

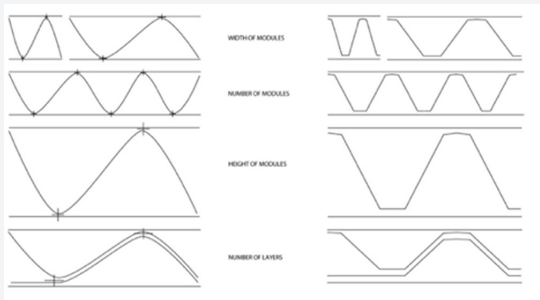
The concept of scalability becomes crucial for a comprehensive understanding of the potential and limitations of designs that emerged from the studio. For example, while most projects showed significant potential of emergent designs at the smaller scale of component design and assembly systems, the same concepts faced limitations of feasibility and constructability when applied too literally on a relatively larger scale of architectural applications. Nevertheless the formal and material experiments lead to the development of specific formal repertoires and to “real” (physical) constraints in the constant translation between computational and physical models. Some of the studies resulted in multilayered architectural models with complex spatial relations (Figure 4).

MATERIAL EXPERIMENTS

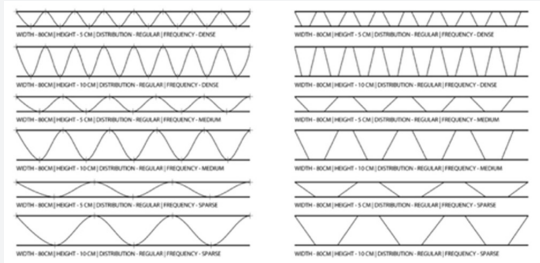
Academic Research

Through a series of physical test cases and design prototypes, the research derives fabrication processes that coalesce the two performative goals of improved structural capability and user-based functionality. Morphologically, the hierarchy of the lamination layers plays a crucial role in determining the global form of the assemblies in addition to governing the structural and spatial behaviour. Hence, the experiments conducted are focused on using this property of hierarchy of layers to modulate the performative properties of assemblies. In a first stage the studies focus on the rules, behaviour and effect of existing uniform hierarchy. This phenomenon of uniformity is then tweaked to develop a concept, for which the term **dynamic hierarchy** is coined, wherein the strict order and differentiation of layers is intercepted to generate a complex intra-connected and interchangeable hierarchical layering system.

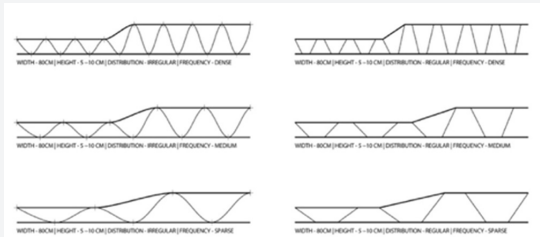
This novel approach to the conventional sheet lamination process opens a plethora of unexplored morphology design solution space having a wide range of effective applications. The two significant fabrication aspects of investigation of construction of these **dynamically hierarchical laminated sheet assemblies** are production and assembly



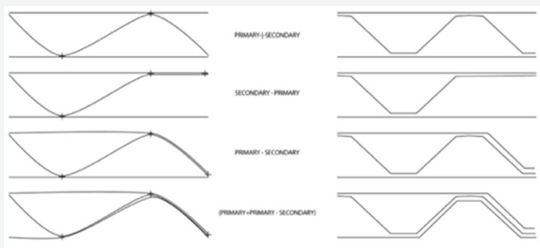
▲ Figure 5: Variations of corrugated core layers.



▲ Figure 6: Variations of uniform core layers



▲ Figure 7: Gradually varying thicknesses in the core layers by changing the distance between fixation points.



▲ Figure 8: Dynamic changes in layer hierarchies.

processes. While studying the assembly system, the research explores potential design applications of incremental scales as test cases and proof-of-concept of the on-going investigation.

Variables/ Parameters

For the sake of nomenclature simplicity and ease of understanding of the system behaviour, we consider sheet layers with a fixed length and width. In the context of this paper, a module is defined as a single bent or folded geometry and an assembly is the term used to describe multiple modules connected using lamination processes. Hierarchy is the term used to describe the sequence of arrangement of layers (main layers defining the global form versus subordinate layers sandwiched between the main layers). The variables or parameters experimented with were firstly, horizontal distance between the connections of modules; secondly, the vertical distance between the connections of modules and thirdly, the number of sheet materials forming the modules. The variation in these parameters subsequently resulted in respective variation in the number of modules within a fixed length of assembly (Figure 5).

Uniform Hierarchy + Uniform Deformation

The natural hierarchy established in the assemblies is based on essentially the function and position of the subordinate layers. The outer layers which governed the global form were the main layers while the core layers sandwiched between the two outer boundary main layers determined the thickness, strength and flexibility of the assembly. The first stage of study involved “uniformly” varying only the height and/or width of the core layer modules. Thus a series of morphologies produced exhibited uniform hierarchy and uniform deformation (Figure 6).

Uniform Hierarchy + Non-uniform Deformation

The next layer of variation in the study was introduced by keeping the hierarchy still uniform, but transforming the core layer modules non-uniformly. The core layers were deformed in varying heights and/or widths (keeping the number of layers constant) and the corresponding effect on the outer main layers was studied. The global form immediately re-morphed based on the amount of variation in the core layers. The global form and the main layer morphology, thus is the function of core layer parameters. The width, height, number and change in these parameters of the core layer modules significantly determined the strength, curvature and flexibility of the entire assembly. This property was the principle driving factor of the further research as it can be now used to manipulate and control the overall characteristics of the assembly (Figure 7).

Dynamic Hierarchy + Uniform Deformation

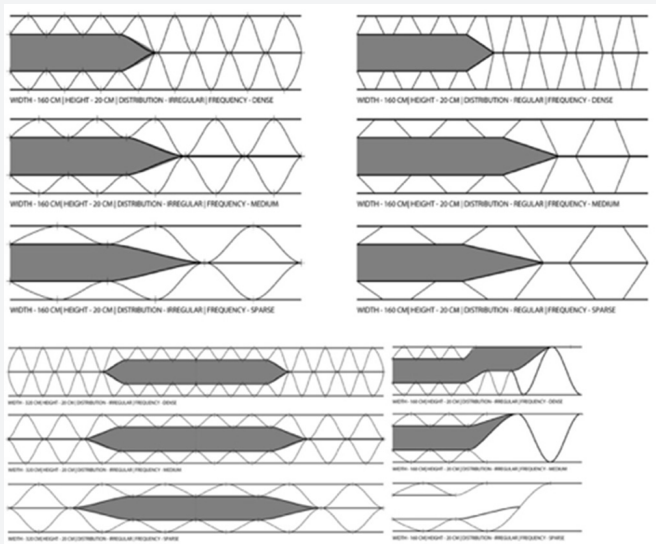
The next stage of investigation involved exploring the possibility of non-uniform hierarchy. This concept essentially involves moving away from the strict differentiation and categorisation of the assembly layers. The aim was to study the results emerging from the possibility of switching the role of layers from being core layers to main layers throughout the assembly. As observed earlier, the core layers determined the characteristics of the main layers and the assembly. So if the roles are switched, the main layers would become the core layers within the assembly while the originally core layers would emerge as the main layers defining the global form. This dynamic hierarchy introduced displays the potential of the assemblies performing as integrated systems emergent from material properties, component morphology and connection methods. This added complexity makes the laminated sheet assemblies system non-linear expanding the domain of design solution space exponentially (Figure 8).

Spatial Cavities from Combinations in Assemblies

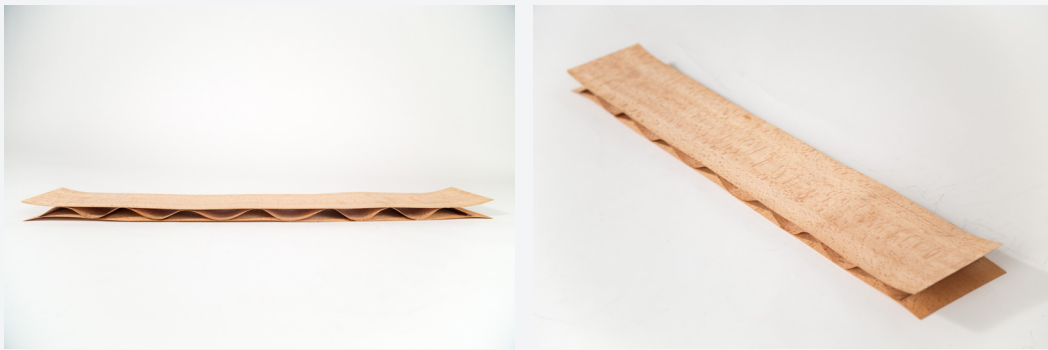
The next stage of experimentation involved exploring the potential of architectural applications by introducing spatially usable characteristics. In order to use the variation in core layers (that resulted in variation in global form) as the tool to carve out spaces, a number of assemblies were now connected with each other (after mirroring in position). The results displayed varying cavities emerging based on alignment and positioning. Upon analysis, this concept displayed multiple advantages that enhanced the performance of the system. Spatially, the cavities had the potential of being usable for multiple purposes like storage, visual connection etc. based on the scale. However, structurally, these cavities helped in material reduction while maintaining the strength of the system. Based on the geometries, some of the cavities enhanced even the stability of the assemblies. For example, the assemblies with diametrically symmetrical cavities had enhanced stability and load bearing capacity compared to the assemblies with asymmetrical cavities. This is because the symmetrical cavities maintain the centre of gravity within the system. The resultant morphologies thus exhibited self-stability with potential of various architectural applications. Furthermore, numerous formal explorations were possible from limited layers and/or parameters. These characteristics of improved spatial and structural performance in addition to material optimization were primary motivations of further research into the subjects (Figure 9).

Physical Experiments

The aim of the next set of experiments was to test the hypothesis and reaffirm the inferences derived from the explorations thus far. The experiments were categorised into physical and digital based on the medium used. However, the process followed was reciprocal wherein the physical experiments assisted the digital set-up and vice versa. The approach aimed



▲ Figure 9: Integration of cavities into the layer assemblies.



▲ Figure 10: Veneer studies

at being more integrative rather than discriminative in order have coherent and efficient results.

The physical experiments aimed at studying the effect of tangible material properties on the assembly structure and morphology. Although these material properties can easily be simulated digitally to predict the behaviour of the system, factors such as material quality, gradation, sequence of making etc. which have a significant impact on the result are rarely taken into account in the digital environment. Moreover, the physical experiments revealed a number of real-world limitations faced during the fabrication of these assemblies, especially while working with different materials.

Paper

Paper, being homogenous material was chosen to work with mainly because it is rarely considered and strong and stable building material by itself. The challenge was to test if the concept of lamination induced considerable amount of strength and stability in the assemblies. Various prevalent parallel fields of modular paper-architecture were also briefly investigated; for example “Origamics” by Marco Hemmerling (*Digital Folding in*

Architecture) and interactive kinetic folded structures by Filipa Osorio (*Interaction with Kinetic Folded Surface*). The experiments we followed, however, were aimed to study the fundamental principles and structural benefits of folding/curving laminated layers through varying geometrical parameters. The improved structural performance in the resultant modules as listed below showed promising potential in emergent behaviour exhibited by laminated sheet assemblies.

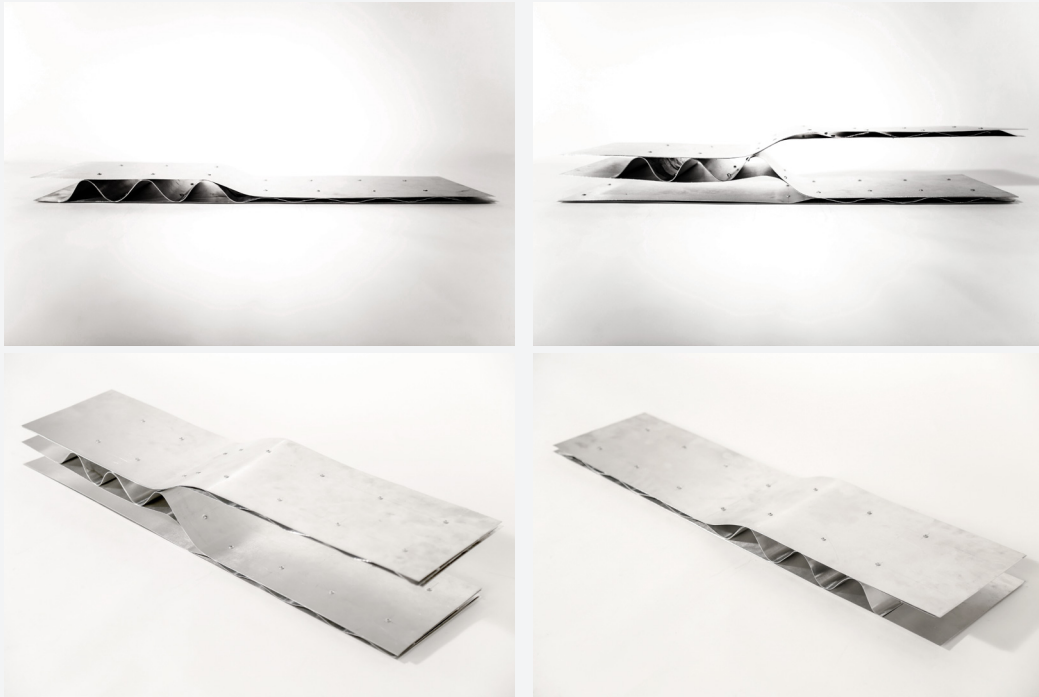
Veneer

Veneer sheet material was the only anisotropic material experimented with in the research. Interestingly, the results emerging from working with the veneer models showed maximum impact of subtle changes and variation (and even errors) in the core layers on the global form and overall behaviour of the laminated sheet assemblies. As anticipated, the orientation of the veneer sheets and its grains played a significant role in determining the strength, stability, flexibility and durability of the resultant morphologies. The goal was to study the relationship between the parameters and resulting characteristics in order to design improvised connection systems. For example, as the width of the sheets increased, the connections failed in overcoming the brittleness of the veneer in lateral direction. The solution to this limitation was provided by cutting the width of the veneer along the grain orientation and then bending the resultant lesser width veneer components more flexibly along its natural curvature. This strategic solution facilitated in not just improving the flexibility of the assembly in lateral direction, but also turned out to be beneficial from design point of view (Figure 10).

Metal

Metal, which is widely used as cladding material, in antithesis to previous notions of steel being the “bones” of architecture wherein it expressed strength and sturdiness, now reveals a softer, highly sculptural, and almost textile quality when used as skins. Metal is also widely getting explored at its compositional level through texturising, a process that improves rigidity through increase in cross sectional depths of thin gauges in addition to adding aesthetic appearance. Interestingly, innovative methods of fabrication in steel construction have been explored both formally and fabrication-wise. An apt example of such research is in the field of incremental sheet metal forming using robotic tools (Kalo and Neswum, 2014). In addition to conventional bending, folding and curving, concepts like creasing and double twisting are also being investigated as ways of maximizing structural performance. Even studies on forming partially doubly curved surfaces out of flat sheet material through 3-D puzzle approach bring to light the plethora of architectural applications emerging from use of digital fabrication processes on sheet materials (Kilian, 2010). This research, while taking inspiration from the parallel studies in metal sheet construction, brings back the focus on the concept of hierarchical layered assemblies (Figure 11).

The aluminium sheet assemblies displayed more strength and load bearing capacity compared to the corresponding paper and veneer modules. The homogenous nature of the material also served in reducing the limitations faced due to orientation and/or grain direction. However, due to the inherent malleable nature of the metal sheets, there was considerable amount of undesirable deformation at the connections and during manual fabrication of the assemblies. These errors, however, could be well avoided by adapting a complete digital fabrication process using water-jet milling, drilling and robotically assisted assembly set up.



▲ Figure 11: Aluminium studies with varying thicknesses (top images) and dynamic hierarchies in the layer assembly (bottom images).

Digital

The digital platforms and tools like Rhino3D and Grasshopper were used to explore the design space emerging from the concept of dynamic hierarchy. As a conscious decision, the design process not entirely computed digitally or automated through programming. The main reason for this strategic move was to restrict the research moving into the direction of becoming primarily a form-finding exercise, thus maintain the focus on lamination process and architectural applications. The digital explorations thus followed a fairly intuitive design development with an underlying goal of exploring architectural usability. The fixation points determine the deformation of single sheets within the elastic range of the material (Figure 12).

The explorations below are limited to 4 layers of sheets within the lamination assembly. The top and bottom layers always maintain the function of being the main layers thus defining the base of the global form of the assembly. The remaining two layers, however, switch between being a main structural layer to being supporting core layer and vice versa. Inarguably, a slight variation in this dynamic hierarchy now results in a large variation in the resultant of the global form, strength and stability (Figure 13).

CONCLUSION AND OUTLOOK

Review and critique on the studio outcomes displayed promising emergent-design potentials, especially from the view of structural and spatial assemblies. The intelligent crafting of material components to strengthen and spatialise the 2-dimensional flat sheets with the help of digital design and fabrication resulted in designs that opened an array of research premises to study laminated sheet assemblies. For example, evaluating laminated



▲ Figure 12: Waterjet cut and digitally predetermined configurations.



▲ Figure 13: Dynamic changes in layer hierarchies, waterjet cut and assembled without material deformation (material stays within the elastic range of deformation).

assemblies on the basis of variation in layering, transformation (bending/ folding etc.) and in fabrication techniques helped in understanding the merits and limitations of various transformations v/s available fabrication tools.

The observed categories in the studio became then central in determining constraints and defining the main parameters of the explorations carried out in further research. It also inspired to maintain the focus of research on simple techniques and an incremental introduction of complexity through experimenting with basic parameters such as the number of layers, and connection rules. Thus process of joinery and system of connections became a crucial constraint to the research, both for its morphological and its structural implications. Further experiments will be conducted by the integration of structural

simulation and mathematical evaluation into the computational models. The physical experiments will be expanded by the examination of multi-material assemblies and composite materials.

ACKNOWLEDGEMENTS

This research is funded by the Singapore University of Technology and Design and the Singapore Ministry of Education. The design studio projects illustrated were conducted in 2015 with the following undergraduate students: Amanda Yeo Qian Yu, Amaryllis Seah Hsueh Ting, Ao Chin Wen, Chia Hui Min Louise, Chiew Jia En, Clover Chen Yutong, Goh Yi Qian, Lim Yan Ling Eileen, Melissa Lim Huay Hsien, Nguyen Minh Chau, Soh Chin Yih, Toh Hui Ping Anna, Xia Tian Summer.

REFERENCES

- Ahlquist, S. & Menges, A.: 2011, Methodological Approach for the Integration of Material Information and Performance in the Design Computation for Tension-Active Architectural Systems, eCAADe 29, Ljubljana, pp. 799-808.
- Cabrinha, M.: 2005, From Bézier to NURBS: Integrating Material and Digital Techniques through a Plywood Shell, ACADIA 2005, Savannah, pp. 156-169.
- Kalo, A., & Newsum, M.: [2014]. An Investigation of Robotic Incremental Sheet Metal Forming as a Method for Prototyping Parametric Architectural Skins, Robotic Fabrication in Architecture, Art and Design 2014, pp. 33-49.
- Kilian, A.: 2010. Fabrication of Partially Double- Curved Surfaces out of Flat Sheet Material Through a 3D Puzzle Approach Fabrication of Partially Double- curved Surfaces out of Flat Sheet Material Through a 3D Puzzle Approach, ACADIA 2003, pp. 75-83.
- Lavallee, J., Vroman, R. & Keshet, Y.: 2011, Automated Folding of Sheet Metal Components with a Six-axis Industrial Robot, ACADIA 2011, Banff, pp. 144-151.
- Pigram, D. & McGee, W.: 2011, Formation Embedded Design a methodology for the integration of fabrication constraints into architectural design, ACADIA 2011, Banff, pp. 122-131.

From continuous to discrete fabrication

Gilles Retsin, Manuel Jimenez Garcia, Vicente Soler

The Bartlett School of Architecture, UCL, UK

MIND THE GAP

With an exponential increase in the possibilities of computation and computer-controlled fabrication, the idea of an architecture of extreme detail and resolution becomes feasible. This possibility has been extensively explored by designers such as Benjamin Dillenburger and Michael Hansmeyer. It became one of the conceptual drivers in the work of practices such as Biothing and TheVeryMany. SoftKill's *Protohouse* project (2012) is also an early exploration of an architecture with extreme detail. The advantages of increasing the resolution of architecture are manifold. According to Dillenburger and Hansmeyer, *"3D printing introduces a paradigm shift in architecture, where the amount of information and complexity of the output is no longer a relevant constraint"* (Dillenburger and Hansmeyer. 2013). Architecture can start to respond in a very precise way to structural criteria or external forces and demands. An increased level of detail also offers new opportunities for aesthetic exploration.

The increase in computational power, availability of industrial robots in academia and distribution of programming knowledge has accelerated computational design research in the past few years. Mass Open Online Classes (MOOC) and other initiatives such as the *Plethora Project* have made it relatively easy for generations of students and researchers to pick up even more complex code. Research in advanced fabrication has increasingly become more accessible.

However, although it is now feasible to build up complex simulations with millions of particles, the resultant simulations are often disconnected from the actual fabrication process. There is a gap between the digital design process and the fabrication method. This paper will further argue that this gap exists as a result of a misalignment between the machine and the design process. Often, simulation doesn't take fabrication into account and designers or researchers prefer to post-rationalise the resultant forms. The possibility of a more holistic approach, where a designer is in control of both the computational design process and the fabrication is an evolution which has only become feasible in recent years with the proliferation of new robotic technologies and digital knowledge.

Mario Carpo divides the past 20 years of digitally intelligent architecture into a first and second digital age. The first digital age, with people like Greg Lynn, Bernard Cache and Zaha Hadid; is interested in the idea of continuity. Architecture is understood as a continuously evolving body - a kind of embryo developing under the pressure of an external field of forces. To become



▲ 3D printed chairs – RC4 204-15 // Team CurVoxels: Hyunchul Kwon, Amreen Kaleel and Xiaolin Li.

reality, the organic, continuous forms of the first digital age had to be subdivided into CNC-milled panels and frames. The first digital age remained a “paper architecture” as it had no intrinsic link with concepts of fabrication. In contrast, the second digital age understands computational processes as fundamentally discrete. EZCT explored this idea of discreteness through their design of a voxel-based chair. However, just as in the first digital age, this second digital age of “big data” is in intrinsic trouble with tectonics and materialization. To materialize the second digital age’s discrete explorations, continuous fabrication techniques are required: cnc-milling molds or 3D printing. This causes a misalignment between the computational method, which is able to negotiate millions of particles, and the hermetic constraints of these continuous fabrication processes. To translate the complex structures generated in the simulation, data often has to be reduced to a series of slices, contours or layered toolpaths.

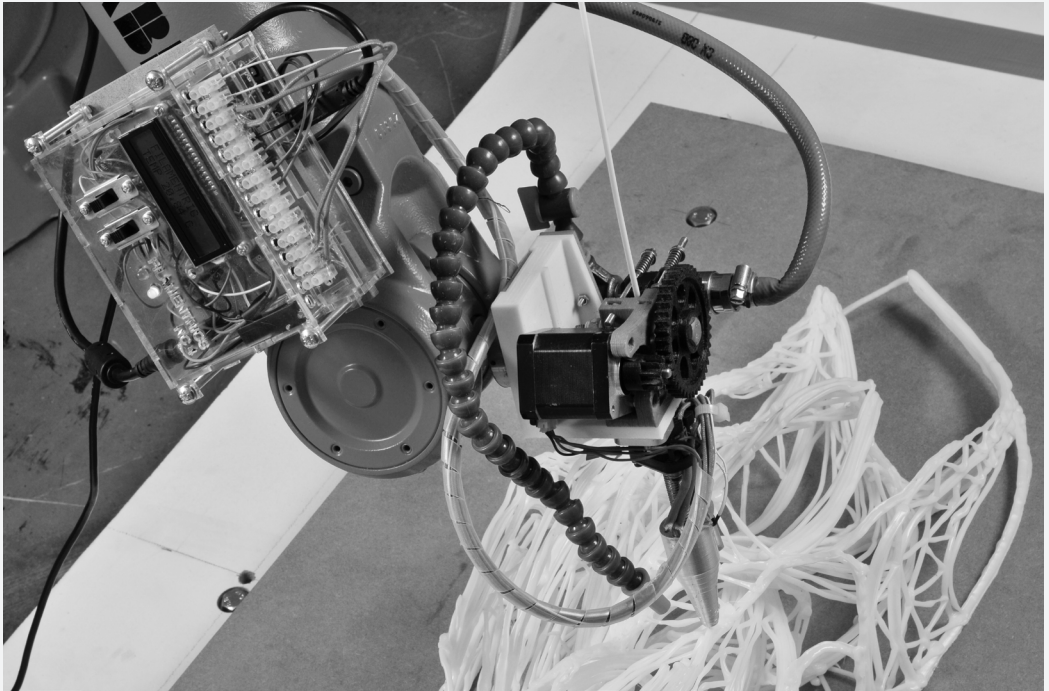
The translation to physical form

reduces the complexity of the structures, effectively removing information. Since the actual organisation of material has not been computed in the simulation, it remains a post-rationalised process. The work presented in this paper attempts to negotiate this gap, by introducing machine constraints as generative drivers of the computational process. The research attempts to establish a one to one relationship between the organisation of digital and physical data.

This paper will describe in detail how this gap can be negotiated within a fabrication framework based on continuous 3D printing. The first iteration of projects described uses continuous computational systems to integrate fabrication constraints within the design method. The second iteration of this research attempts to utilise discrete computational models. As a brief introduction, a third iteration will be introduced, which proposes discrete methods for both computation and fabrication.

TOWARDS LARGE SCALE ADDITIVE MANUFACTURING

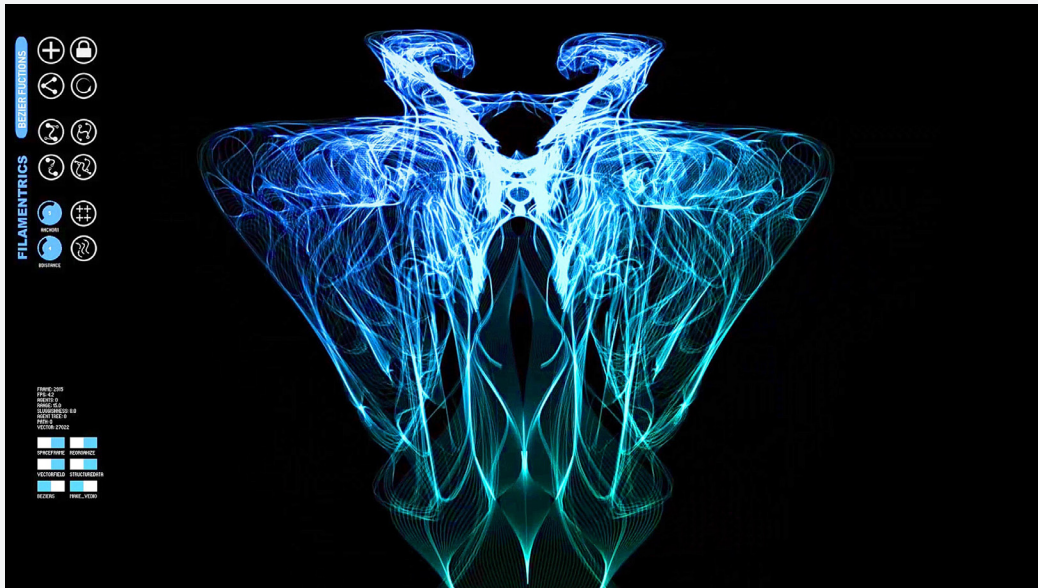
The projects described in this paper are produced in a research-through-teaching context at Research Cluster 4 (RC4) in the Bartlett School of Architecture, UCL. RC4 is a part of B.PRO, an umbrella of post-graduate programs in architecture at the Bartlett. The cluster is led by Gilles Retsin and Manuel Jiménez García, and started out in 2013. Since the start of the cluster, there has been a close collaboration with Vicente Soler. From the early stages, the research agenda of RC4 has focused on large scale additive manufacturing



▲ Robotic printing - The Bartlett RC4 2013-14 // Team Filamentrics: Nan Jiang, Yiwei Wang, Zheeshan Ahmed, Yichao Chen

for architecture. The research makes use of industrial robots, which are turned into 3D printers by attaching custom designed end-effectors for additive manufacturing. This effectively turns industrial robots into large format 3D printers. RC4 is part of a larger body of research in large scale printing. Large scale 3D printing for architecture is often associated with Behrokh Khoshnevis' Contour Crafting procedure. Contour Crafting enables the printing of large scale concrete structures from a gantry structure. A similar process developed by WinSun in Shanghai has entered the commercial market, producing a large number of full scale prototypes in the past few years. Enrico Dini's D-Shape printer is also based on a large gantry, but it uses a binder to solidify stone dust into a sandstone-like material. While these precedents successfully innovative with the development of a machine, they are not innovative with the design methodology itself. They are effectively investigating only one side of the gap - the fabrication process. On the other hand, the research by Dillenburger and Hansmeyer is specifically focused only on design, and not on fabrication. They assume the existence of a large scale 3D printer, using a commercially available printer such as the Voxeljet sand printers.

There are a number of important precedents using robots as 3D printers. By using a robot, researchers can skip the expensive and slow process of developing a new, large scale machine from scratch. IAAC research led by Marta-Male Alemany was the first to focus on robotic processes for additive manufacturing in an architectural context. Gramazio and Kohler's research at the Future Cities Laboratory in Singapore was the first to introduce spatial plastic extrusion with a robot arm. Outside of architecture, the aerospace industry has been investigating metal sintering processes with robots.



▲ Applet Screenshot - The Bartlett RC4 2013-14 // Team Filamentrics: Nan Jiang, Yiwei Wang, Zheeshan Ahmed, Yichao Chen

Research in RC4 starts out with the choice of a specific material and printing process. Students start the research by exploring material properties. For instance, in the case of concrete or plastic, the material is tested for consistency of extrusion, through a series of manual tests. As a second step, students develop a custom-built extruder. This extruder is then first manually tested, and later on mounted on a robot. Multiple iterations of the tool head are developed. Over the past two years RC4 developed more than seven iterations of a plastic filament extruder, gradually increasing speed and precision. The designs of this extruder are available for a next generation of students to further develop. The tool is always intrinsically linked with a chosen material for printing. RC4 has developed tools for robotic 3D printing in clay, plastic, sand, concrete and timber.

Students synthesize the computational process for tool path generation in a small applet, programmed in Processing. The applet has a graphic interface for users to interact with the complex set of constraints related to the fabrication process. The applet fuses all the code necessary to generate the tool-path into one single process, which is visualised as a design environment. It allows designers to quickly generate possible versions of their work, in a more playful way, without being overly constrained by fabrication. RC4 research advocates the idea that architecture should develop its own algorithmic methodologies, based on constraints from the fabrication process, rather than borrowing methods from natural systems. Most of the algorithms underlying the work of the second digital age [Carpo, 2012], such as recursive subdivision, fractal growth, cell-division, agents or reaction-diffusion are driven by observations into natural systems. The algorithms can be considered “found objects”, which don’t take into account constraints relating to materialization, structure or constructability.

This paper will discuss a gradual shift from continuous to discrete computation using four projects, spread over two years of research. Filamentrics and CurVoxels, which are based on lightweight plastics; and Microstrata and Amalgama, which are based on compression



▲ Rendering - The Bartlett RC4 2013-14 // Team Filamentrics: Nan Jiang, Yiwei Wang, Zeeshan Ahmed, Yichao Chen

materials such as concrete. The first two projects take on board the idea of spatial extrusion of plastics, rather than printing in layers. Filamentrics is based on a continuous computational method which uses an agent-based algorithm to develop toolpaths in space, in response to a field of forces and specific ideas of structure. CurVoxels uses the same fabrication technique of spatial printing, but changes the computational method to a discrete method based on voxels. While these two projects investigate lightweight, space-frame like structures which mainly operate in tension, the next two projects are based on heavy, wet processes utilising compression-based materials. Microstrata developed a D-Shape like process of powder printing, where sand is solidified with a binder, resulting in heavy, strong, sandstone-like blocks. The next iteration of that project, Amalgama, replaces the sand for actual concrete. A powder based support bed is used to support layers of extruded concrete, allowing for more formal freedom, such as large cantilevers.

CONTINUOUS COMPUTATION

Filamentrics

Filamentrics [Zeeshan Ahmed, Nan Jiang, Justin Yichao Chen, and Yiwei Wang] investigated spatial 3D printing of space-frame like structures with a high degree of differentiation. The project is based on a 3D version of a classic FDM (Fused Deposition Modelling) process. Instead of printing in layers, hot plastic is extruded along a vector and cooled down with cold air to solidify quickly in space. There has been a number of precedents for these kind of processes, mainly with small scale 3D printers. The G-Code or machine input is modified by the designer to work in three dimensions. This process was first brought to a robot for the project Mesh-Mould, by Gramazio Kohler at the ETH/Future Cities Lab in Singapore in 2012. An FDM-like extruder is attached to a robotic arm, and used to extrude a mesh-like structure which is then used as a formwork for a semi-liquid kind of concrete.

Filamentrics aims to 3D-print heterogeneous space-frame like structures, where material is organised according to principal lines of stress. The material organisation also responds to

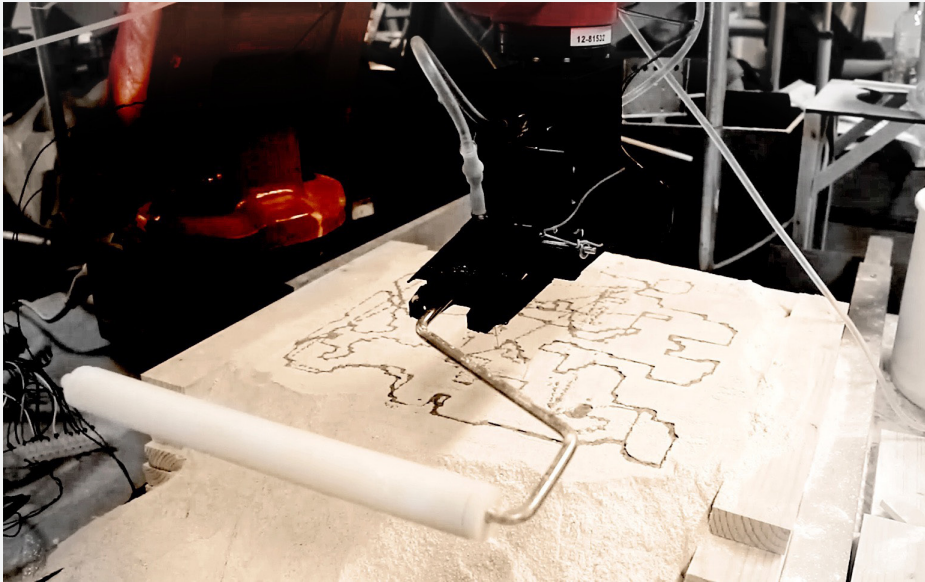


▲ Physical prototype - The Bartlett RC4 2013-14 // Team Filamentrics: Nan Jiang, Yiwei Wang, Zheeshan Ahmed, Yichao Chen

other types of structural data such as the amount of stress. To achieve this heterogeneity and adaptability to structure-data, an agent-based system was used. Principal lines of stress are translated as a vector field, which can be implemented and read by a series of agents. While maneuvering the vector-field, the agent creates a toolpath trajectory for the robot. The agent gets a series of constraints which relate to the constraints of the fabrication process. For example, it's prevented to self-intersect with existing lines. A minimum and maximum distance between trajectories is also constrained. In a subsequent stage, a second set of agents connects the previously generated lines together. These triangular connections are again subjected to a series of constraints. The lattice-like structure in between lines is constrained by a specific angle under which the nozzle would intersect with the deposited material.

The organisation of these trajectories responds to the amount of stress through bundling: where there is a high level of stress, lines start to cluster together. The designed structures are initially generated as a whole, but can then be broken down into designed pieces which fit the maximum workspace of the robot. This process of generation is entirely scripted in a Processing-based applet. Once the structure is generated, it's exported as a text-file to Rhinoceros/Grasshopper. HAL is used to generate the actual machine code to drive the robot, and communicate with the extruder. As a final output, a 3 x 2.5 x 2.5m pavilion was printed. It consisted of 26 pieces generated by the applet developed for the project.

The generative process takes a number of constraints into account, but the resultant structures still need a large amount of time to solve errors, intersections and singularities. Due to the heterogeneity and large amount of variation in the generated toolpaths, it's difficult to automate the post-rationalisation. Problems and errors are, just like the structure itself, continuously different and require unique solutions. This means that the file preparation becomes time-inefficient. The nature of this problem lies in the continuous character of the



▲ Robotic Fabrication – RC4 203-14 // Team Microstrata: Wonil Son, FaFame Boonyasit, Maho Akita & Syazwan Rusdi

generative process. Errors can't be serially solved, and large amounts of time or computational power is needed to prevent them from occurring. The continuous nature and interdependency of the agent-trajectories also fundamentally doesn't allow for a local problem solving. If a problem occurs, the whole system has to be rerun to solve it.

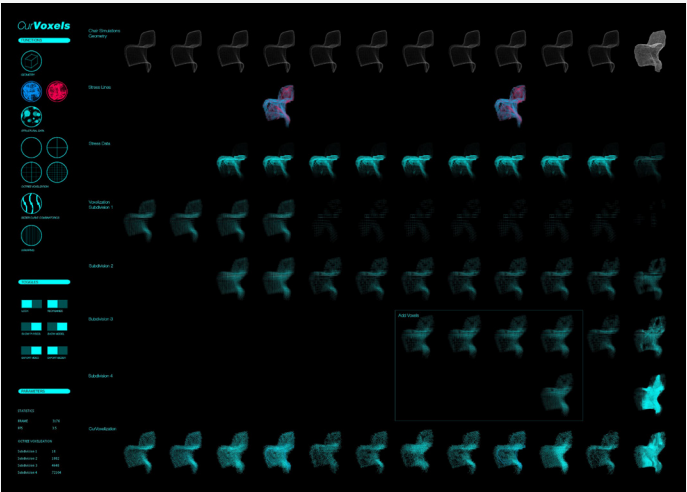
MICROSTRATA

Microstrata (Maho Akita, Fame Ornruja Boonyasit, Syazwan Rusdi and Wonil Son) uses the opposite kind of materials to Filamentrics: heavy, compression based sandstone. The project is based on a powder-printing process, similar to Enrico Dini's D-shape. A layer of sand is spread out and flattened by a custom made end-effector on the robot. The nozzle itself consists of a needle connected to a valve, which drops binder. The custom-developed software for this research project understands every drop of binder as computable matter. The team adopted an approach based on voxels or three-dimensional pixels, in combination with an agent-based system. In a similar way as Filamentrics, agents are used to distribute and organise a network of connections. In this case two different types of agents are developed, one which reacts to tension and one to compression. This network is then effectively voxelised. Voxels containing compression data trigger the end-effector to deposit binder, whereas tension areas remain empty. The data generated by the processing applet is effectively just a voxel containing a boolean statement to open or close the nozzle valve. At a later stage, aluminium is cast inside the cavities left by the tension network.

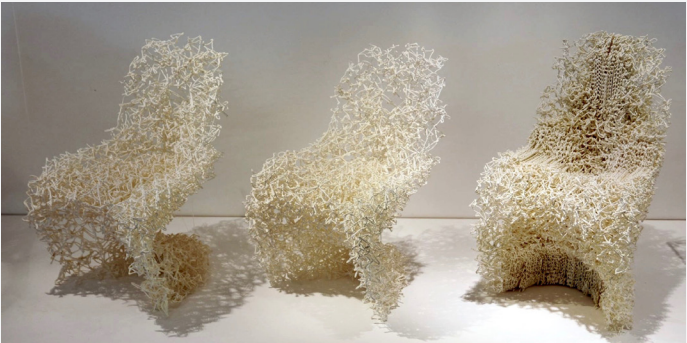
To give an example, for building an enclosed tension channel, 8 voxels need to be bound together. The size of one voxel or drop of binder is 4 x 4mm. To achieve these types of precise typologies, a Cellular Automata logic is developed, which can expand the initial voxel and form channels or bridges. The compression network develops as solid zones, reacting to amounts of stress. In areas with high stress levels, a thicker cluster of voxels is



▲ Physical prototype – RC4 203-14 // Team Microstrata: Wonil Son, FaFame Boonyasit, Maho Akita & Syazwan Rusdi.



▲ Applet Screenshot – RC4 204-15 // Team CurVoxels: Hyunchul Kwon, Amreen Kaleel and Xiaolin Li.



▲ 3D printed chairs – RC4 204-15 // Team CurVoxels: Hyunchul Kwon, Amreen Kaleel and Xiaolin Li.

generated. This process resulted in a series of porous sand-stone structures, connected with a capillary network for tension material.

Compared to Filamentrics, Microstrata employed a less linear and continuous fabrication process. Although the material distribution is continuous, the voxel and CA logics introduce a degree of discreteness in the process. The process of preparing robotic control data in Grasshopper proved to be simpler. The CA logics were relatively efficient at problem solving.

DISCRETE COMPUTATION

Taking on board the problems associated with continuous, generative processes, the second iteration of research, conducted during the academic year 2014-2015, focused fundamentally on discrete computational processes.

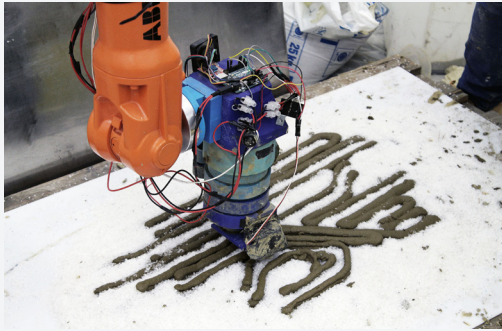
CurVoxels (Hyunchul Kwon, Amreen Kaleel and Xiaolin Li) continued the spatial printing research from Filamentrics, but focused on a voxel-based combinatorial logic to generate the toolpath. The team continued the development of the plastic extruder initiated by Filamentrics, adding higher torque motors and a better cooling system. A *combinatorics* algorithm is used to aggregate a single curvilinear element into a continuous, kilometres-long extrusion, which allows for an uninterrupted printing process.

An initial shape is *voxelized*, taking structural forces as a driver for the distribution of voxels. The size of the voxels changes in response to the amount of stress, distributing different material densities. When voxels are very small, the embedded spatial curve effectively becomes no more than a line. What appears to be two different formal syntaxes, curvilinear versus linear, is actually the product of a single spatial curve on different scales. The system works by calculating tangents and points of connectivity to other voxels from the curve of a single voxel. Each discrete voxel unit has 24 possible rotations, which enables it to generate a differentiated, heterogeneous pattern. Converting a curve into a discrete voxel unit enables quick evaluation of printability with a high level of control over patterns. The fundamental advantage of this serial approach is that a toolpath only has to be optimised and tested for one voxel, in 24 different rotations. Afterwards, thousands of these voxels can be aggregated, but the connection problems remain finite and manageable.

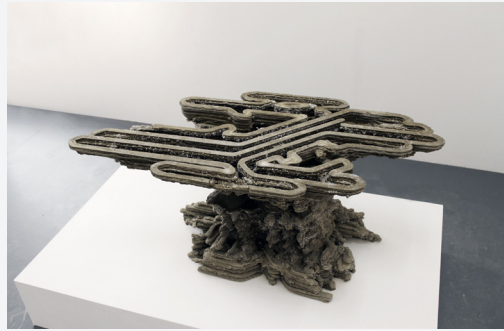
AMALGAMA

Amalgama (Fran Camilleri, Nadia Doukhi, Alvaro Lopez Rodriguez and Roman Strukov) develop a project based on the agenda of printing compression based structures. In this case, the fabrication method combines two already existing concrete 3D printing methods: extrusion and printing. This combination of techniques has given rise to a form of supported extrusion. Concrete is extruded layer by layer over a bed of granular support material. Due to the support, the resulting extruded concrete is of a much higher resolution, and large cantilevers are achievable. The supported extrusion method developed by Amalgama gives designers more formal freedom and less constraints, while introducing more variation in, what is traditionally, a layered concrete extrusion processes.

The team also developed a *combinatorics*-based code, where every voxel has a specific type of pattern inscribed on its face. The voxels rotate into a position which establishes a continuous pattern. In a second stage, this two dimensional pattern is grown into a three dimensional volume with a smaller kind of voxel. In a last iteration, these small scale voxels are assigned a discrete part of the toolpath with a random start position. These discrete pieces of toolpath are then connected into the longest continuous line possible, within one layer of the structure.



▲ Robotic Concrete 3D printing – RC4 204-15 // Team Amalgama: Francesca Camilleri, Nadia Doukhi, Alvaro Lopez Rodriguez and Roman Strukov.



▲ 3D printed concrete Table – RC4 204-15 // Team Amalgama: Francesca Camilleri, Nadia Doukhi, Alvaro Lopez Rodriguez and Roman Strukov.

NEXT STEPS

RC4 engaged for a cycle of two years with the idea of 3D printing large scale structures. The third iteration, which is ongoing, investigates the advantages of shifting to a discrete fabrication method, rather than a continuous one. 3D printing can be considered a continuous method, as it continuously glues or melts particles together, with an infinite connection scheme. Continuous fabrication processes have intrinsic problems with fundamental issues such as speed, structural performance, multi-materiality and reversibility. Discrete or “digital” fabrication processes are based on a small number of different parts, having only a limited number of options for connecting together. The design possibility, or the way how elements can combine and aggregate is defined by the geometry of the element itself - which leads to a “tool-less” assembly. The geometry of the parts being assembled provides the dimensional constraints required to precisely achieve complex forms.

Aligning discrete computation with discrete fabrication, enables the designer to bridge the gap between the digital and the physical. Digital Data is the same as physical data. The physical organisation of matter becomes “digital”, in the sense that it maintains its discreteness and the potential to be re-assembled.

Discrete fabrication has the same type of advantages in terms of problem-solving as discrete computation: problems are serialised and solutions therefore become repeatable and cheap. The fundamental problem of 3D printing lies in multi-materiality: a process of voxel-assembly can deposit infinite variations of material. Rather than using robots as 3D printers, this next phase of research uses robots as voxel-assemblers or voxel-printers. robots quickly pick and place discrete bits of matter, assembling it into heterogeneous aggregations.

FROM CONTINUOUS TO DISCRETE

The research in the first year of RC4 research started out with design methodologies based on continuous computational systems such as agent-based algorithms. These were used to simulate the deposition and organisation of material in space, a process which is then translated to the robot. This workflow led to a few observations: the translation from a continuous system to a set of toolpaths for the robot is often very time consuming and still needs post-rationalisation. The continuous systems become increasingly computationally expensive. To incorporate all the constraints from the printing process in a continuous toolpath requires heavy computing and a large amount of memory.



▲ 3D printed staircase – RC4 2014-15 // Team CurVoxels: Hyunchul Kwon, Amreen Kaleel and Xiaolin Li.

These observations have led to a shift towards discrete computational methods in the second year of the research, focusing on computing discrete parts of the toolpaths. These are first generated in one voxel, where all the constraints are optimised and tested. In a second stage, a large number of voxels are combined together into one continuous path. This method only requires local computation, and is as such computationally inexpensive and quick. The prototyping aspect also becomes much quicker, as only one voxel has to be checked for problems. Rather than continuous differentiation, heterogeneous structures were achieved by always rotating the piece of toolpath contained in the voxel into different positions. These discrete approaches prove to be successful. The serialisation of the discrete toolpath patterns means that there is a reduction of unique problems to solve. One fragment of the toolpath can be optimised, and then serially repeated and combined into a larger toolpath. Continuously generated toolpaths have a complicated and large amount of unique connection problems, each of them requiring a different solution to become a printable structure.

To overcome the risk of generating rather homogenous structures due to the serial repetition of voxels, the idea of *combinatorics* was used. Through continually rotating the discrete element in different positions, highly heterogeneous and differentiated structures became feasible. This is a fundamental shift in digital design thinking: from mass-customization and continuous differentiation, to discrete, serially repeated systems which can still maintain a high degree of heterogeneity. This approach not only brings the feasibility of printing digitally intelligent structures a step closer to reality, but also makes 3D printing more accessible. As problems are serialised and easy to solve, there is no need for expensive problem solving equipment such as advanced sensors, camera trackers or supercomputers.

REFERENCES

- Dillenburger, B., Hansmeyer, M., 2014. Printing Architecture: Castles Made of Sand. Fabricate 2014. Zurich: ETH pp. 92-97
- Sanchez, J., 2014. Post-Capitalist Design: Design in the age of acces. Paradigms in Computing: Making, Machines, and Models for Design Agency in Architecture. Los Angeles: eVolo Press. pp. 112-122
- Carpo, M., 2014. Breaking the Curve: Big Data and Design. Artforum. pp. 169 - 170
- Kasapantoniou, S., 2014. Computational Chair Design using Genetic Algorithms by EZCT Architecture & Design Research. [online] Available at: <http://www.academia.edu/8171471/Computational_Chair_Design_using_Genetic_Algorithms_by_EZCT_Architecture_and_Design_Research> [Accessed 7 Jan 2016].
- Retsin, G., 2015. Discrete Assemblage as Design and Fabrication Strategy. TxA Emerging Design + Technology, 5-7 November 2015, Dallas. [in print, 2016]
- Khosnevis, B., Contour Crafting, University of South California. [online] Available at: <www.contourcrafting.org> [Accessed 7 Jan 2016].
- Malé-Alemany, M., FABbots: Digital Fabrication on-site. [online] Available at: <<https://fabbots.wordpress.com/>> [Accessed 7 Jan 2016].
- Hack, N., Lauer, W., Gramazio, F., Kohler, M., 2014. Mesh-Mould. AD 229, 84 Made by Robots: Challenging Architecture at a Larger Scale, pp. 44-53.
- Cranfield University, 2013. Revolutionary 3D metal production process developed at Cranfield. [online] Available at: <<https://www.cranfield.ac.uk/About/Media-Centre/news-archive/news-2013/Revolutionary-3D-metal-production-process-developed-at-Cranfield>> [Accessed 7 Jan 2016].
- Jimenez Garcia, M., Retsin, G., 2015. Design Methods for Large Scale Printing. ECAADE : Real time, 16-18 september 2015, Vienna: Technical University of Vienna. pp. 331-339
- Hack, N., Lauer, W., Gramazio, F., Kohler, M., 2014. Mesh-Mould. AD 229, 84 Made by Robots: Challenging Architecture at a Larger Scale, pp. 44-53.
- Jimenez Garcia, M., Retsin, G., 2015. Design Methods for Large Scale Printing. ECAADE : Real time, 16-18 september 2015, Vienna: Technical University of Vienna, pp. 331-339
- Schwarz, T., HAL Robotics Ltd, 2015. [online] Available at: <<http://www.hal-robotics.com>> [Accessed 7 Jan 2016].
- Ward, J., 2010. Additive Assembly of Digital Materials. PHD Thesis, Massachusetts Institute of Technology

