Prototyping Protocell Mesh

Michael Stacey & Chantelle Niblock

> "The slightly drifting, labyrinthine spaces that these meshwork and filter systems make might seem far from proudly framed public chambers, but they do offer tangible gathering spaces amidst their multiple hollows and creases."
> Philip Beesley[1]

1 Chantelle Niblock, Building with Beesley, in *Prototyping Architecture: the conference papers* edited by Michael Stacey Riverside Architectural Press 2013, p.296

This book chapter is primarily written by the architecture students of The University of Nottingham Department of Architecture and Built Environment describing their experience of prototyping and installing *Protocell Mesh* over a two year period at the three venues of Prototyping Architecture Exhibition in Nottingham and London in the United Kingdom, and Cambridge, Ontario in Canada. The three essays incorporated into this chapter provide distinct perspectives on working with Philip Beesley.

Prototyping Architecture Exhibition, curated by Michael Stacey, explores the importance of prototypes in the delivery of high quality contemporary architecture - performative architecture that is inventive, purposeful and beautiful. Focusing on construction that is informed by aspiration, knowledge and material culture, *Prototyping Architecture* places a particular emphasis on research and experimentation showing how trial assemblies can inform architecture. In post-digital design practice the prototype remains a vital means of design development, setting out impending systems and material futures with the potential for technology transfer from other industries. It highlights the role of low carbon architecture and offsite manufacturing in maximising the effective use of materials and resources, whilst delivering environments that facilitate human well-being.[2]

2 Michael Stacey, *Prototyping Architecture*, Riverside Architectural Press. Canada, 2013, P3.

facing page
3 Protocell Mesh, Nottingham, 2012

Omar Kahn, one of the co-chairs of ACADIA 2013, observed, "This exhibition is a retort to sceptics who claim computational technologies are reducing architects' engagement with materials and making. To the contrary, it celebrates the incredible creative production that results from experimenting with new technologies and techniques to push the boundaries of architectural design"[4] .

4 Omar Kahn by *email to the authors* August 2013.

The students' engagement with *Protocell Mesh* was facilitated by their studio tutors Dr. Chantelle Niblock, who runs the Digital Architecture and Fabrication Studio [DAFS] at Fifth Year MAch/Diploma, and Professor Michael Stacey, who convenes Making Architecture Research Studio [MARS] at Sixth Year MAch/Diploma. Both these studios are based on design research and are directly linked to our research group at Nottingham, Architecture and Technology Research Group (ATRG). The primary mode of design research in MARS is making[5], and considering how the decisions related to architecture develop as physical realisations. Sverre Fehn eloquently states, "all architecture is dependent on construction. Construction seeks the earth; it falls upon it. The eye, light, and thought, that which spatially disturbs these words, [is] construction"[6].

5 Michael Stacey, Frances Stacey and Laura Gaskell, *Studio MARS Brief 2013-14*, University of Nottingham, 2013

6 Quoted by Per Plaf Fjeld, *The Pattern of Thoughts*, 2009, Monacelli Press, p182

MAKING WITH PHILIP BEESLEY

Emma Eady, Vikash Patel and Dominic Ward[7]

7 Emma Eady, Dominic Ward and Vikash Patel, *Studio MARS Making and Field Research Report*, University of Nottingham, 2014, pp. 41-69.

Prototyping Architecture Exhibition

During our 5th year at the University of Nottingham, we were involved in the construction of the *Protocell Mesh* installation for the Nottingham and London venues of the Prototyping Architecture Exhibition. The MARS field trip to Canada included assembling the Mesh for the final stage of this exhibition in Cambridge Galleries. As part of this field trip we were invited to visit Philip Beesley's architectural practice in Toronto as he encourages students to participate in the construction of his projects. The development of team building and understanding of the manufacturing process through making becomes as much a part of the end result as the three-dimensional space.

Protocell Mesh

Protocell Mesh is constructed from a series of chevron shaped components that are arranged to form a suspended meshwork canopy[8]. The meshwork is primarily composed of aluminum and acrylic scaffolding that, held under tension, creates a flexible, hyperbolic grid shell[9]. This structure then supports suspended filters containing a protocell carbon capture chemistry. The

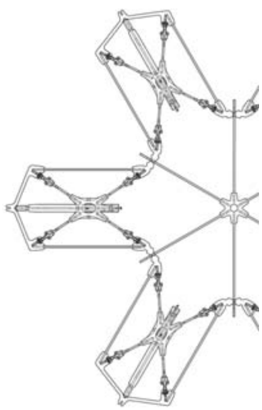
facing page top

8 Suspended chevron mesh canopy

9 Ohrstedt P., and Isaacs H., eds., 2010. *Hylozoic Ground: Liminal Responsive Architecture*, Philip Beesley. Cambridge: Riverside Architectural Press.

structure consists of three layers; the acrylic/aluminium lily structure, the ghost layer and the protocell chemistry. Philip Beesley describes his designs as an engineered landscape; "an artificial layer that extends and supports a living system"[10]. The mesh becomes a new artificial scaffold to support the near-living chemistry. These ideas experiment with the possibilities for a future façade that is adaptive to its surroundings.

10 Ohrstedt P., and Isaacs H., eds., 2010. *Hylozoic Ground: Liminal Responsive Architecture*, Philip Beesley. Cambridge: Riverside Architectural Press.



11 Two dimensional drawing of an assembled "ghost" element

Our initial encounter with *Protocell Mesh* had been at the end of September 2012. A set of diagrammatic plans were given to demonstrate how our project had been explored two-dimensionally[11]. These were to be the instructions to produce the complex three-dimensional space. Students felt there was an amazing contrast between the simple instructive diagrams and the final intricate mesh. The diagrams were flat and informative allowing us to engage with the construction process simply, creating a dialect between architect, constructor and user. The simplicity exaggerates how the materiality and configuration of the project is key to its visual impact.

Fabrication began at the University of Nottingham, with acrylic components being laser cut in the Built Environment's Centre for 3D Design with aluminium components cut in Derbyshire by FC Laser. True file to factory production, which bypassed the Atlantic Ocean, the unit group of 15 students, was split into groups of 3 and 4 to begin assembly of the acrylic lilies. After a series of successful generations, a system of standardised sets of parts had been developed with a tested laser-cut snap-fit joint. Whilst on the site visit to Beesley's practice in Toronto, he explains, 'Methodology in the initial production focuses on the component itself, clarifying and refining the composition[12]. This proved to be fundamental to the mesh's successful construction, given the construction team's unfamiliarity with the initial design.

12 Ohrstedt P., and Isaacs H., eds., 2010. *Hylozoic Ground: Liminal Responsive Architecture*, Philip Beesley. Cambridge: Riverside Architectural Press.

The modular structure consists of slightly varying acrylic 'bones' that are used multiple times in varying positions to create the structural mesh layer. This methodology has regularly occurred within the sculptural pieces. The chevron link acts as the core piece in the structural mesh; once clicked into place, the single component can create a carpet structure that resembles a woven textile. The use of tessellated geometry of hexagonal and rhombic arrays creates a symmetry and regular tiling system. By progressively connecting the pieces, complex lily forms are created that, once fixed together, form the scaffolding for the chemistry systems that hovers below.

Thousands of components were delivered, with parts systematically organized for the launch of the construction. As in a typical manufacturing line, sub-assemblies were formed by groups constructing the different fragments of the structure. This allowed us to break down the instructions and focus on perfecting a methodology for each individual aspect of the construction, accelerating the process. A classroom in the gallery was transformed into a working assembly line. The system allowed the group of students to assign roles and manage themselves; we became a small working community, commonly working with the same end goal.

The acrylic components snapped together with a system that did not require any fasteners; the aluminium components utilized a slot fit joint relying on tension to keep the form. Cable ties were often needed to hold the aluminium chevrons in place until the umbrella tension rods could support the lily scaffold.

By working closely with both materials it was clear how they had foregone a thorough exploration of the material qualities, manipulating the acrylic and metal to allow for bending and compression under tension.

After the intense two-day lily assembly workshop, we began hanging the structures from the roof of the Woolfson exhibition hall. The process required us to work as teams to adjust the heights of the lilies and, once elevated, fix them together. Specialised acrylic joints were attached to allow the acrylic 'ghost layer' to clip onto the mesh and hang the protocell systems. After six days, the team had finished construction of *Protocell Mesh.*

their ability to design a set of components to produce an amazing mesh system that is both visually attractive but structurally smart demonstrates that through rigorous prototyping and analysis an architecturally coherent finalised product can be produced. The meshwork design allows for ease of transportation and installation both nationally and internationally, demonstrating a flexible system that proves adaptive to change and reconfiguration. This allows for further expansion and development where new prototypes can be easily accepted. The process allowed a group of students to become a successfully functioning construction community. Much like many complex buildings, as a large three-dimensional structure, is it hard to comprehend how it is made. Through a method of interaction with singular components, a body of knowledge began to develop through an understanding of material limitations, layering compositions and making.

PROTOCELL MESH AT PROTOTYPING ARCHITECTURE EXHIBITION: THE CAMBRIDGE EXPERIENCE

Peter Blundy, Samuel Critchlow and Michael Ramwell [13]

First assembled in Nottingham, 2012, the installation made its way to Cambridge Ontario (via London) for its final display at the University of Waterloo Architecture, Cambridge, Ontario.

Protocell Mesh integrates first-generation prototypes that include aluminium meshwork canopy scaffolding and a suspended protocell carbon-capture filter array. The scaffold that supports the installation is a resilient, self-bracing meshwork waffle composed of flexible, lightweight chevron-shaped linking components. Curving and expanding, the mesh creates a flexible hyperbolic grid-shell[14]. The installation very subtly moves or expands in response to human occupancy through a chemical process of capturing the carbon dioxide exhaled and converting it into calcium carbonate.

This is a fascinating idea, however in practice the mesh's flexibility is limited and instead can be appreciated aesthetically and intellectually as a beautifully evocative conceptual piece. These works may be in their early stages, however it is an interesting venture relevant to our current times of technological innovation. Concepts fundamental to the installation involve scale and component production. Currently, the application of the research

13 Peter Blundy, Samuel Critchlow and Michael Ramwell, *Material and Culture*, University of Nottingham, 2014, pp.247-264.

14 Michael Stacey, *Prototyping Architecture*, Riverside Architectural Press. Canada. 2013, p.59

remains at the scale of a non-structural installation within an existing building. However, the component work does show theoretical promise for applications within architecture.

The Problems of Components

Breaking a constructed element down into a series of standardised components has many advantages[15]. One advantage is that, often, the way that the components are designed to fit together means that they may also be easily disassembled and reassembled (this is of particular benefit to temporary structures and installations). However, one of the counter-problems to this advantage is that, under the strain of such a tectonic act as construction, there may be permanent distortion applied to the component itself, making it difficult or impossible to disassemble and reuse. This was evidenced during our assembly of *Protocell Mesh* as the installation had been constructed previously, on two separate occasions.

15 Assembled array of Philip Beesley's acrylic chevrons

Structural Innovations

Innovations to the *Protocell Mesh's* structure are currently in development at Philip Beesley Architect Inc. New scaffold structures have been developed from lasercut acrylic, with radial slot-like perforations, which is heated and subsequently expanded using a manual rig. Following the introduction of aluminium with Nottingham's 2012 collaboration, the studio has also experimented with similar aluminium structural components.

Where Michael Stacey observed of the studio's work in 2007: 'They taken one process, laser cutting, and two materials, acrylic and mylar, to produce an inventive and immersive three-dimensional installation cut from flat stock sheets and using minimum material with the minimum of waste[16]. This is now being extended by project-based research and development, replacing hundreds of hand assembled components making a rigid structural mesh with single expanded components. These new forms still originate from sheet material but are fully formed into three dimensional components of future meshworks.

16 Michael Stacey, From Flat Stock to Three-Dimensional Immersion, in: Philip Beesley, ed. *Kinetic Architectures and Geotextile Installations*, Riverside Press, p.62, 2007. Second Edition 2010.

CRAFTING: FROM THE PRIMITIVE TO THE DIGITAL: REFLECTING ON THE BODY OF WORK OF PHILIP BEESLEY

Dominic Ward [17]

With the beginning of the Industrial era, the context in which crafting existed changed forever. The crafters of trade; stone masons, carpenters and many more, had previously crafted products of necessity. With increasing competition from industrial machines, the crafters struggled to provide services and craft products as efficiently and as cheaply as their contemporary counterparts. As Adamson argues, "Artisans were drummed out of work by machines, with tragic consequences both for the experience of the makers themselves and the quality of the things they produced"[18]. This was combined with a fear that crafting would be lost forever and in response the Arts and Crafts movement was formed. Influential individuals, such as William Morris, championed a revival of crafts and challenged a total reliance on the industrial system.

The Arts and Crafts movement was born out of a growing concern about Britain's rapid industrialisation. The leading art and social critic, John Ruskin believed that increasing industrial manufacture was having a profound effect on the creative arts and British society on a whole. Ruskin theorised that "without dignified, creative human occupation people became disconnected from life"[19]. He wanted British workers to have pride in the work they produced and promoted the revival of traditional crafting, encouraging a return to a "simpler way of life"[20]. This simplification corresponded almost harmoniously with Augustus Welby Norhmore Pugin's two great rules for design[21], outlined in the first chapter of his written lectures, *The True Principles of Pointed or Christian Architecture*:

> First, that there should be no features about a building which are not necessary for convenience, construction, or propriety; second, that all ornament should consist of enrichment of the essential construction of the building.[22]

Now with the birth of the digital age, comes an even higher level of competition. Today, the innovation of technology means industry can create the most intricate of products. Traditional crafting of the past is yet again being challenged by these new technologies. The aim of this discussion is to consider the role of corporeal "hands-on" crafting and ascertain whether there is still a place for this in a time when digital processes continue to be an established tool in both the design and making of architecture.

17 Dominic Ward Craft in *Contemporary Architecture*, University of Nottingham, 2014

18 Glenn Adamson, *The Invention of Craft*. London: Bloomsbury Publishing Plc, 2013, p. XV.

19 Fiona MacCarthy, Morris, William (1834–1896), designer, author, and visionary socialist. In: *Oxford Dictionary of National Biography* (online ed.). Oxford University Press, 2009.

20 Ibid.

21 Augustus Welby Northmore Pugin, *The True Principles of Pointed Or Christian Architecture*: Set Forth in Two Lectures Delivered at St. Marie's, Oscott. [e-book] London: W. Hughes. Available at: Google Books <https://play, google.com/store/books/details/Augustus_Welby_Northmore_Pugin_The_True_Principles?id=SKhLAAAAMAAJ> [Accessed 1 January 2014], 1861, p. B.

22 Ibid.

Defining Crafting

The reference to skill and the hand has become synonymous with the today's idea of crafting. Towards the end of his introduction to *The Invention of Craft*, Glenn Adamson profoundly states that to him, "craft has always meant something like making something well through hand skill," no more and no less[23]. Such a broad definition covers a vast array of skilled activities, from a local village baker to the master stonemasons of ancient Rome.

In *The Craftsman*, Richard Sennett eloquently introduces crafting by describing a carpenter's workshop[24]. Although he later goes onto discuss the topic in all its various forms, the carpenter, a well-known artisan, serves as a tangible analogy for crafting. It is the notion of the well-practised hand of the carpenter and the knowledge learnt through years of experience.

While it is clear that skilled manual work, developed through years of tactile experience, can be defined as crafting, the notion of crafting today encompasses a much wider collection of activities. In *Re:Crafted*, Marc Kristal explores the unconventional notions of craft and defines it on a much broader sense, "a method of making that combines a vast store of skill-based knowledge"[25]. This simple definition of the term does not confine crafting to the physical, nor does it reference the context of making. Despite the author's attempt, Kristal goes onto explain that even this broad description isn't enough to define the modern perception of crafting.

Amidst the new digital era with automated methods of production the modern definition of crafting has become almost infinite. The simple reference to hand and skill does little to contain our perceptions. A well trained digital designer surely possesses skill and the products of their work have been produced by hand, even if this may be through the interaction with a computer. It could be argued that the simple reference to skill and hand is a passive attempt to define something, which constitutes far more in the contemporary world we live in.

Digital Era

Comparable to the questions provoked by the Industrial Revolution, the new digital era has brought to question the position of crafting and its role in design. The relationship between the designer, the maker and the product has become even more blurred. Years ago, architects would laboriously sketch

23 Glenn Adamson, *The Invention of Craft*. London: Bloomsbury Publishing Plc., 2013, pXXIV.

24 Richard Sennett, *The Craftsman*. London: Penguin Books, 2008, p9.

25 Marc Kristal, *Re:crafted: Interpretation of Craft in Contemporary Architecture and Interiors*. New York: The Monacelli Press, 2010, p6.

multiple drawings and make beautifully crafted physical models, realized in final representations and taken to site. The architect's physical interaction with each process kept them engaged with each project and encouraged a sense of pride in a final product. The architectural design process can now almost all be performed by "the lowing of keys and clicking of mice"[26]. Even the final construction stage can be performed by the machine, through the advancement of manufacturing technologies; Professor Behrokh Khoshnevis, from the University of Southern California, believes he has created a large concrete printer capable of printing a house in under a day [27].

26 Michael Stacey. Digital Craft in the Making of Architecture. In: Bob Sheil, ed. 2012. *Manufacturing the Bespoke*. West Sussex: John Wiley & Sons Ltd. pp58-76.

27 Business Standard. New 3D Printer Can Build a House in 24 Hours. [online] Available at: *<http://www.businessstandard.com/article/pti-stories/new-3d-printer-can-build-a-house-in-24-hours-114011200280_1.html>* [Accessed 12 January 2014]

As the capabilities of the computer have increased, they are increasingly relied upon in architectural design. There are arguably many merits in using digital technologies in the process of design. For one, the chance of human error can be radically reduced. A more obvious benefit is the speed and efficiency in which visions can be explored and represented. There have been huge developments over the last few decades, from the two-dimensional computer-aided design (CAD) to three-dimensional programs such as Rhino. These programs have a vast array of uses in architectural design, from the initial proposal stage to the point of construction. Hand-models can now seemingly be replaced by their digital equivalents or even printed by additive manufacturing; a process in which layers of material are printed to produce a physical three-dimensional model. With these advancements, there is an increasing fear that an over reliance on CAD may lead to designers not participating in learning and developing the intuition gained from physical craft [28].

28 Richard Sennett, 2008. *The Craftsman*. London: Penguin Books. pp19-52.

It is important to remember that the design of architecture demands an understanding that is both tactile and tangible. It is because of this that architectural design of the present era has shifted its focus onto the practice of making. This new era has been defined by the ever developing characteristics of digital design. The work produced using CAD has led to the architect assuming the role of both designer and maker [29].

29 Bob Sheil. 2005. Design Through Making: An Introduction. *Design Through Making*, 75 (4). p7.

Michael Stacey, a professor of architecture and the University of Nottingham, focuses on the digital craft of architecture. He poses the question, "Can the digital design of architecture be considered a craft...?"[30] This questions stems from many of the traditional understandings of craft, which focus on the production of a physical and tangible product. It could be argued that the mouse and keyboard serve as the maker's tools. In the same way a carpenter carves a piece of wood, the architect carves the ones and zeroes of digital

30 Michael Stacey. Digital Craft in the Making of Architecture. In: Bob Sheil, ed. 2012. *Manufacturing the Bespoke*. West Sussex: John Wiley & Sons Ltd. pp58-76.

space. The final product, although not always existing in the physical, has still been devised through the process of thought and hand. From this, it appears that the problem does not lie with the tool of the architect, but lies within the removal of a direct haptic relationship between the maker and the made leading the criticism of digital craft. This also adds to the complexity of how one can define crafting in its truest sense. To address his question, Stacey refers to Sennett's proposition of Linux software as a type of craft. Devoid from any physical output, Sennett suggests the software programmers become engaged with their work, gaining a sense of pride through the development of their skill[31]. Although it is easy to agree with Stacey's suggestion that "a totally cerebral digital crafting of architecture is possible"[32], is this the best practice for the training architect, or does there need to be a more physical interaction with the materials they work with?

31 Richard Sennett, 2008. *The Craftsman*. London: Penguin Books. pp24-28.

32 Michael Stacey. Digital Craft in the Making of Architecture. In: Bob Sheil, ed. 2012. *Manufacturing the Bespoke*. West Sussex: John Wiley & Sons Ltd. pp58-76.

Further Thoughts

In response to Chantelle Niblock asking Philip Beesley his view of the success of the prototype protocell system within Prototyping Architecture, he responded:

> "We developed *Protocell Mesh* with our collaborators, working up to the last moments before opening the exhibition, refining details and adjusting jointing systems, and setting up a new filter system that we hadn't seen working at this scale before. The prototype aluminium meshwork system that we developed together with the school showed tremendous promise for its sheer strength and its tolerance for wide distortions. The glasswork 'reticulum' of lightweight valves and filters showed strong calcium-carbonate precipitate formations, directly demonstrating carbon capture operating. In those ways, I'd say the work was a resounding success. On the other hand, the jointing systems took quite a bit of wrestling and even a bit of blood in the laborious hand-work of their assembly. Next generations for this system will be much more refined, concentrating on making things 'finger-friendly' and faster to assemble.[33]"

33 Chantelle Niblock, Building with Beesley, in *Prototyping Architecture: the conference papers* edited by Michael Stacey Riverside Architectural Press 2013, p.291

Installations are one of the very few experimental frontiers of contemporary architecture; by prototyping *Protocell Mesh* we were taking risks in time and resources, small sums stretched to achieve the maximum, and small groups of students learning by doing journeying beyond the normal confines of studio in terms of time and space. Ultimately, *Protocell Mesh* pushes the boundaries of current architectural expression, exploring possible future architectural spaces based on diffusive interaction.

facing page

34 Aerial view of the completed Protocell Mesh, Nottingham (2012).