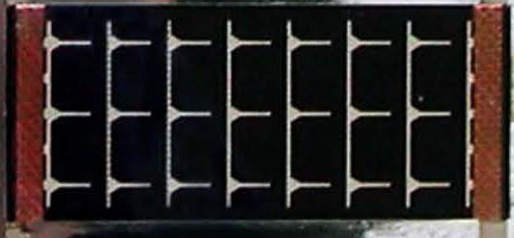
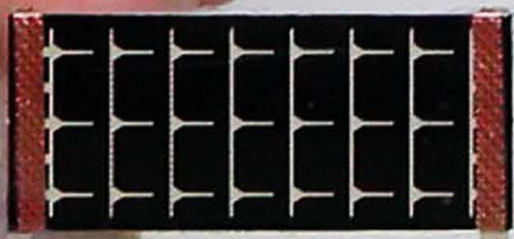
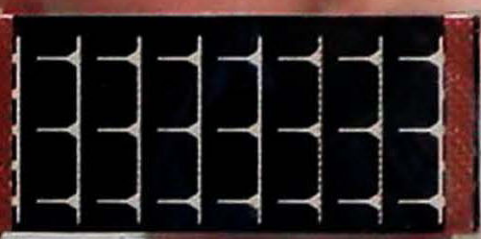
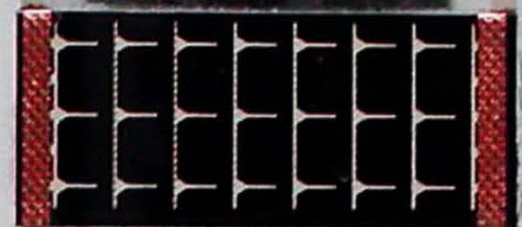
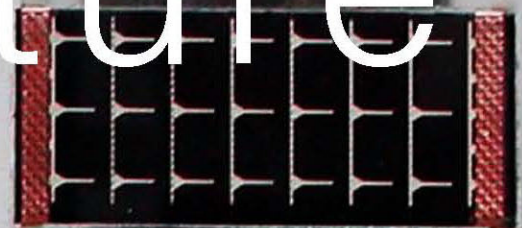


Procell Mesh

By Philip Beesley

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Prototyping Architecture



Michael Stacey

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Includes essays by international leaders in contemporary architectural prototyping and design and documents the exhibition Prototyping Architecture, which was inaugurated at Wolfson Hall, University of Nottingham, 2012, and then shown at the London Building Centre Gallery, 2013, where it was accompanied by the international conference Prototyping Architecture. The final stage of the exhibition is at Design at Riverside, University of Waterloo, 2013 for the ACADIA 2013 Adaptive Architecture international conference, Cambridge, Ontario.

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The Architecture & Tectonics Research Group at the University of Nottingham with The Building Centre Trust, London and Cambridge Galleries and Waterloo Architecture are pleased to present this book, which explores the importance of prototypes in the delivery of high quality contemporary architecture - performative architecture that is inventive, purposeful and beautiful. Maximising the effective use of materials and resources whilst delivering environments that facilitate human well-being. This book accompanies and records the Prototyping Architecture Exhibitions in Nottingham, London and Cambridge, Ontario. This set of exhibitions has evolved venue to venue for site specific reasons.

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Prototyping Architecture Exhibition

17 October to 7 December, 2012
Wolfson Prototyping Hall,
Nottingham, UK

10 January to 15 March, 2013
The Building Centre,
London, UK

17 October to 17 December, 2013
Cambridge Galleries,
Ontario, Canada

Curator
Michael Stacey
Michael Stacey Architects
+
University of Nottingham



The University of
Nottingham

S4AA:
Cymru

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Foreword

Spencer de Grey¹

This book, appropriately digital, has been prepared to accompany the *Prototyping Architecture* exhibition at the Building Centre, London. On the 10 January 2013, I was delighted to open this exhibition in my role as Chairman of The Building Centre Trust. For me, this is an incredibly important exhibition, prototyping and research has been at the heart of everything we've done in the office and it's wonderful to see so many interesting, innovative and exploratory ideas assembled here. Some of the technologies and techniques an architecture or engineer can take away and use tomorrow in practice, others will stimulate our intellect and our desire to progress in months and years to come. It's a very interesting cross section of a wide range of different ideas and approaches, so I think it is an extraordinarily interesting array of different components and materials. These have been sourced from the leading edge of world architecture, situated both in practice and in university research teams. Components in this exhibition will challenge perceived ideas about material science, others present the potential for the printing of metal components, Additive Manufacturing to transform construction.

Mike Stacey has been at the centre of arranging and putting on this exhibition, it started at Nottingham University where he is Professor. Mike worked with us back in the 80's in particular on the HongKong Bank, Renault Centre and Stanstead Airport - so it's very nice to renew our relationship once again with him. This quality of exhibition and the related conferences; TEST conference for teachers and researchers in Architecture, particularly Technology, Environmental Design & Sustainability [TEST] and the Prototyping Architecture International Conference helps to place The Building Centre at the heart of contemporary discourse on construction and architecture.

(Endnotes)

¹ Spencer de Grey Head of Design at Foster + Partners and Chairman, The Building Centre Trust.

Introduction

Michael Stacey



‘Work stops at sunset. Darkness falls over the building site. The sky is filled with stars. “There is the blueprint,” they say.’

Italo Calvino, *Invisible Cities*¹

This book 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. Written to accompany the *Prototyping Architecture Exhibition* in Nottingham, London and Cambridge, Ontario, 2012-13. *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.

David Leatherbarrow in *Uncommon Ground*, 2000, mourns the death of design perhaps particularly in North America, charting the retreat of architectural practice, “the increased and increasing use of ready made solutions largely transforms design invention into choice, converting creativity into selection.”² Thus diminishing the cultural value of architecture.³ *Prototyping Architecture* demonstrates that inventiveness has not been lost within architecture. Both architecture and technology are malleable in

Fig. 1.1 Protocell Mesh, Philip Beesley Architect Inc, at *Prototyping Architecture*, Nottingham, 2012



Fig. 1.2 Great Workroom of the Johnson Wax Administration Building, Frank Lloyd Wright, completed in 1939

the hands of a well-informed architect. *Prototyping Architecture* illustrates the role of models, prototypes and the printed components in the design of architecture and the built environment, with a particular focus on architecture that is assembled from prefabricated components, where prototyping has particular relevance.

The making of architecture is dependent on ideas and the communication of ideas. If we examine the etymology of 'prototype' we find that it addresses the very core of architecture as generated by typologies.⁴

n 1. An original thing or person of which or whom copies or improved forms, etc. are made.

2. A trial model or preliminary version of a vehicle, machine etc. From the Greek **Prototupos**. **Protos** – first, original. **Typos** – impression, figure, type⁵

Whereas if we look at 'innovation' an overused word of contemporary life, we find the etymology to be:

v 1. bring in new methods, ideas, etc.

2. make changes.

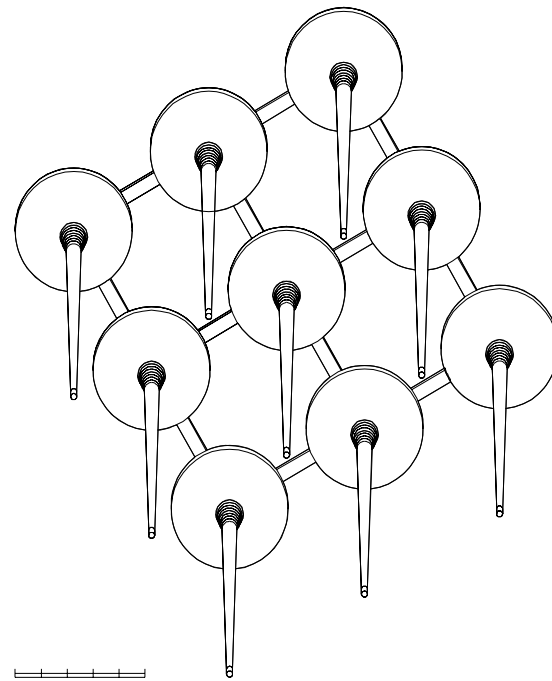


Fig. 1.3 Structural arrangement of the Great Workroom of the Johnson Wax Administration Building



Fig. 1.4 Frank Lloyd Wright witnessing the load testing a prototype concrete column for the Johnson Wax Administration Building

From the Latin *innovatus* 'altered'⁶

Although the definition of innovation contains the notion of new ideas it is much more about transfer or borrowing. There is no need for the original and perhaps this is why governments find it easier to demand. In my view invention, to create by thought, is much more important.⁷

Primo Levi in his novel *The Wench* eloquently describes the creative impulse that resides within construction.

'We agreed then on the good things we have in common. On the advantage of being able to test yourself in your work, not depending on others in test, reflecting yourself in your work. On the pleasure of seeing your creature grow, beam after beam, bolt after bolt, solid, necessary, symmetrical, suited to its purpose and when it's finished you look at it and you think that it will live longer than you, and perhaps it will be use to someone you don't know, who does not know you. Maybe, as an old man, you'll be able to come back and look at it, and it will be beautiful, and it doesn't really matter so much that it will seem beautiful only to you, and you can say to yourself "maybe another man wouldn't have brought it off"⁸

He captures the essence of the maker, of testing ones tectonic ideas. Is it the prototype or its author who is tested within the experimental process of research design and development? Prototypes are a clear demonstration of the iterative process that is essential when designing. Architects and Engineers develop constructional prototypes for six main reasons, to:

- test new ideas as part of an experimental practice;

- extend the boundaries of the known, [including working beyond

current regulations and standards];

- test new holistic assemblies of many parts and components

- researching and generating robust constructional technology;

- test scale and to manifest ideas

- focus cross disciplinary collaboration;

- deliver quality.

The first three types of prototypes fully embrace an empirical scientific method and encompass the potential of failure, which is the failure of the prototype and is the basis of the success of the process. This is a process of prototyping and testing, a process of trial and error. However, within the realm of professional practice there is little scope for failure and it is the duty of 'an experimental' architect to return his or her work to the certain and risk free. Even within the experimental practice of Philip Beesley his work is constrained by the inhabitation of the gallery based installations. Although clearly metaphoric provocations of future action and future architecture, works of architecture that are comparable to the creation of literature, his installations including *Procell Mesh*, remain constrained by many considerations including health & safety. However, all experimentation is now constrained by regulation respecting the health and welfare of the participants.

Examples of prototyping that were essential to realising the proposed architecture include the dendriform or tree-like concrete columns of The Great Workroom of the Johnson Wax Administration Building, completed in 1939 by Frank Lloyd Wright, and Tim Macfarlane's work with Steve Jobs and Seele on the glass stairs and structural glass enclosures of the worldwide Apple stores. Although separated in time by over 60 years both are examples of architects and engineers working beyond the current norms of building regulations and constructional standards. The dendriform columns were outside the building regulations of Wisconsin in the 1930's therefore the structural testing of a prototype column was essential. Robert McCarter records, 'as was typical of Wright's structural innovations, professional engineers and inspectors not only did not understand these columns, they felt that they did not possess the necessary formulas necessary to calculate the indeterminate loads. They therefore opposed [the use of the Lillie columns] when Wright submitted the construction drawings to obtain a building permit in 1937 the Wisconsin State Building Commission was utilising a building code that could not be applied to Wright's design. As a compromise Wright proposed casting and testing a single column.⁹ On 4 June 1937 when the cast concrete was only one week old, not fully cured, the load test was carried with a test load of twelve



2.1 Protocell Mesh

Philip Beesley and Waterloo Architecture



Fig. 2.1.2 The completed Protocell Mesh at Prototyping Architecture, Nottingham, Philip Beesley Architect. Inc.

Architect: Philip Beesley Architect Inc.

Researchers: University of Waterloo, School of Architecture¹

Materials: Bespoke aluminum hyperbolic grid-shell with aluminum and stainless steel details, glass and polymer filter assemblies, protocell chemical inclusions, essential oils.

Location: Wolfson Prototyping Hall, the University of Nottingham.

Exhibit: Protocell Mesh

Philip Beesley's 'work is a very humane response the contemporary condition of ecology. He seeks to progress beyond an abstract Modernism to something richer and more productive.'²

The Protocell Mesh project integrates first-generation prototypes that include aluminium meshwork canopy scaffolding and a suspended protocell carbon-capture filter array. The scaffold that supports the Protocell Mesh installation is a resilient, self-bracing meshwork waffle. Curving and expanding, the mesh creates a flexible hyperbolic grid-shell. The meshwork is composed of flexible, lightweight chevron-shaped linking components. The chevrons interconnect to create a pleated diagonal grid surface. Bifurcations in mesh units create tapering and swelling forms that extend out from the diagrid membrane, reaching upward and downward to create suspension and mounting points. Floating radial compression frames provide local stiffening and gather forces for anchorage. Arrayed protocells are arranged within a suspended filter that lines this scaffold. The array acts as a diffuse filter that incrementally processes carbon dioxide from the occupied atmosphere and converts it into inert calcium carbonate. The process operates in much the same way that limestone is deposited by living marine environments. Within each

Fig. 2.1.1 The completed Protocell Mesh at Prototyping Architecture, Nottingham, Philip Beesley Architect. Inc.



Fig. 2.1.3 Protocell Mesh at Prototyping Architecture, Nottingham

cell of the filter array, laser-cut Mylar valves draw humid air into a first chamber of concentrated sodium hydroxide. The solution enters a second chamber containing waterborne vesicles suspended between upper and lower oil layers. Chalk-like precipitate forming within these vesicles offers an incremental process of carbon fixing.

Surrounding the active flask arrays is a grotto-like accretion of suspended vials containing salts and sugar solutions that alternately accumulate and exude moisture, contributing to a diffusive, humid skin. Scent glands act as lures to encourage occupation of this synthetic aerial soil.

The Protocell Mesh project builds upon component systems that have been developed within the Hylozoic Series, a collaborative project that is pursuing near-living architectural systems combining lightweight flexible structures, interactive distributed computation and protocell metabolisms. The meshwork integrates research from the Universities of Waterloo, Nottingham, and Southern Denmark.

“This architecture is sitting on the frontier of new possibilities; some might say is this art or architecture? In a sense that is not what is important about this piece, it is really in the thoughts and provocations it produces, where its importance lies. It is more like literature than conventional architecture. It is how the imagination of the viewer is stimulated, where the cultural importance of the work of Philip Beesley lies.” Michael Stacey at Prototyping Architecture.³

Notes

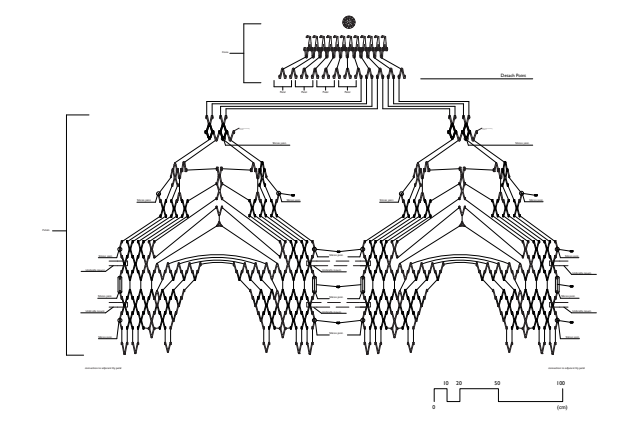


Fig. 2.1.4 PBA Inc.'s drawing of the lilies and how they are assembled



Fig. 2.1.5 Assembling the laser cut aluminium components of a lily



Fig. 2.1.6 RIBA President Angela Brady in the Protocell Mesh at the opening of Prototyping Architecture, London

¹ Primary research for this project are as follows: Nottingham, Architecture & Tectonics Research Group; and Southern Denmark, Center for Fundamental Living Technology Social Sciences and Humanities Research Council, Canada.

² Michael Stacey, *From Flat Stock to Three-Dimensional Immersion* in Philip Beesley, ed., *Kinetic Architecture & Geotextile Installations*, Riverside Press, 2010 p.59

³ To see this video follow the links from - http://www.buildingcentre.co.uk/galleries/galleries_main.asp, posted January 2013

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References

Citation for the above:

Beesley, Philip. "Protocell Mesh." *Prototyping Architecture*. Ed. Michael Stacey. Toronto: Riverside Architectural Press, 2013. Print. 58-61.

For further reading:

Beesley, Philip, Matthew Chan, Rob Gorbet, Dana Kulić, and Mo Memarian. "Evolving Systems within Immersive Architectural Environments: New Research by the Living Architecture Systems Group" *Next Generation Building 2.1* (2015): 31-56. Print.

Beesley, Philip, ed. *Near-Living Architecture: Work in Progress from the Hylozoic Ground Collaboration 2011-2014*. Toronto: Riverside Architectural Press, 2014. Print.

Beesley, Philip. "Dissipative Prototyping Methods: A Manifesto." Guest Ed. Rachel Armstrong. *Journal of the British Interplanetary Society 67.7/8/9* (2014): 338-345.

Beesley, Philip, and Michael Stacey. "An Interview with Philip Beesley and Michael Stacey." *Fabricate: Making Digital Architecture*. Eds. Ruairi Glynn and Bob Sheil. Toronto: Riverside Architectural Press, 2013. Print.

Beesley, Philip. "Prototyping for Extimacy: Emerging Design Methods." *Prototyping Architecture: The Conference Papers*. Ed. Michael Stacey. Toronto; London: Riverside Architectural Press and London Building Centre, 2013. Print.

Beesley, Philip. "Input Output: Performative Materials." *Performative Material in Architecture and Design*. Eds. Rashida Ng and Sneha Patel. Bristol: Intellect, 2013. ix-xi.

Beesley, Philip. *Sibyl: Projects 2010-2012*. Toronto: Riverside Architectural Press, 2012. Print.

Beesley, Philip. *Hylozoic Ground: Liminal Responsive Architectures*. Toronto: Riverside Architectural Press, 2010. Print.

Beesley, Philip. "Case Study: Meshes as interactive surfaces." *Digital Fabrication in Architecture*. By Nick Dunn. London: Laurence King, 2010. 46-48.

Beesley, Philip. "Soil and Protoplasm." *Manufacturing the Bespoke*. Ed. Bob Sheil. London: Wiley, 2010. 102-119.

Beesley, Philip. "Geotextiles." Eds. Sarah Bonnemaïson, and Ronit Eisenbach. *Installations by architects: experiments in Building and Design*. New York: Princeton Architectural Press, 2009. 90-97.

Beesley, Philip, ed. *Kinetic Architectures and Geotextiles Installations*. Toronto: Riverside Architectural Press, 2007 & 2010. Print.

Beesley, Philip. "Orgone Reef." Guest Ed. Bob Sheil. *Architectural Design 75.4* (2005): 46-53.

Beesley, Philip, and S. Hanna. "Lighter: A Transformed Architecture." *Extreme Textiles: Designing for High Performance*. Ed. Matilda McQuaid. New York: Princeton Architectural Press, 2005. 103-137.

Krauel, Jacobo, Jay Noden, and William George. *Contemporary digital architecture: design & techniques*. Barcelona: Links, 2010.

Stacey, Michael. "Digital Fabricators." *Architects' Journal* 219.15 (2004): 31.