Title: **Or, The Thing Itself: Towards a Material Practice in Architecture**
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Time in other words, reappears in the world as something real, as a destabilising but creative milieu.
- Sanford Kwinter[1]

One geometry cannot be truer than another, it can only be more convenient.
- Henri Poincaré[2]

1. The shift from drawing to material

The late 20th century saw an extraordinary, but predictable, revolution in architecture, particularly in the establishment of design research as a legitimate field within the discipline. An unprecedented amount of work by architects validated an interest in tools that came out of the sciences held huge potential for demonstrating novel ways in which one could design architecture, beyond the use of pencil and paper. Architecture was viewed not as teleology, but as a practice which regarded research as an intrinsic part of the process of design: research as design and design as research. Therefore architecture could no longer be viewed only as a static, inert undertaking, embedded with meaning in a top-down fashion, but had the possibility to be a dynamic, fluxing, shifting, complex construct from which meaning emerged. It could be simulated, transcribed and translated in a multitude of ways, and given numerous layers of complexity that involve novel parameters inscribed within the design process. Oftentimes the architects who began to engage with this kind of work were those who were looking at fields related to but outside of architecture: to the work of philosophers, mathematicians, statisticians, cyberneticians, biologists, chemists, metallurgists, et cetera. This can be seen in the work of architects such as Greg Lynn's early simulation studies of pedestrians, cars and other forms of movement for the design of the Port Authority Bus Terminal in New York City (1994), or Reiser + Umemoto's Watergarden for Jeff Kipnis (1997) where they formulated an argument

[1] Kwinter, Sanford. "Landscapes of Change: Boccioni's 'stati d'animo' as a General Theory of Models", *Assemblage*, no. 19 (December: 1992), p 50-65.
[2] Poincaré, Henri. "Non-Euclidean Geometries", *Science and Hypothesis*, 1905.

for 'solid-state architecture' around the word *puissance*, **used by Deleuze in his interpretation of Nietzsche's term.**[3]

Parallel to this was the hypothesising of the relationship between drawing and building by the late Robin Evans, who wrote in his seminal essay "Translations from Drawing to Building" (1997) that the substratum of such translation is a space of opportunity; for invention, manipulation and accidents to occur, very much in the same way they occur in language. One has only to look at the English translations of texts by post-structuralist French philosophers to realise that this is the case, that in any other language meaning becomes construed, manipulated and, oftentimes, transformed. This of course can be interpreted as a positive attribute to the process of translation – as surprises can lead to innovation and the breaking of existing paradigms. What Evans recognised, however, is that within architecture the prevalent language of representation was the two-dimensional drawing. While the drawing could become far removed from the actual *thing itself* **and maintain its importance to the discipline, the result in terms of material practice was that the two-dimensional drawing had found a place in architecture where its representation** *of a thing* **became more important than the 'properties' of the** *thing itself*.[4]

This ran alongside materialist practices in architecture that historically fell primarily into one of two groups: that which *imposed* **lack of material difference in favour of an ideal, and that which** *equalised* **material difference to in order to determine form. The modernist project is the main protagonist in both of these coteries, but one can look back as far as the pyramids, as Le Corbusier did in** *Towards a New Architecture* **almost 100 years ago, to recognise that both have existed throughout the history of architecture. Achieving form was, by and large, a process of forcing inert material to become something the architect wanted it to be. Material was often treated as a passive mono-material, active only when manipulated to achieve an idealised form. For example, in the work of Louis Kahn, brick was viewed as a homogenous series of idealised elements, relatively undifferentiated in their accumulation. However, this is not limited to the work of modernists. One has only to look at the many built projects by Zaha Hadid Architects to understand that this materialist phenomenon is still at work today.**

In the fourteen years since the turn of the millennium, the discipline has registered two shifts. In this essay we aim to outline several problematics that have emerged out of these shifts, each of which we would argue constitutes a revolution in architecture. The first revolution proves the limitations of object-orientated thinking in building and material practices, while the second transforms them. Firstly, the three-dimensional model has slowly become the output of many architecture practices and construction firms, with

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[3] Reiser, Jesse. "Solid-state architecture", *Reiser + Umemoto: Recent Projects* (ed. Andrew Benjamin), London: 1998, p 50.
[4] Evans, Robin. "Translations from Drawing to Building", in *Translations from Drawing to Building and Other Essays* (Architectural Association Publications: 1997), p

object-orientated design (OOD) becoming the norm; in 2012, seventy-one percent of design and construction companies in North America utilised building information modelling (BIM) software.[5] With origins in object-orientated philosophies of science, such as cybernetics and computer science, OOD transforms the two-dimensional drawing into a three-dimensional object embedded with specifications and data for the design of a building. The difference between drawing and building therefore decreases, as the fields of architecture and construction can interpret and utilise the same three-dimensional model, in real-time. However, this is limited to the design process, rather than being extended to methods of construction or fabrication, and still results in the object of architecture, and materiality, being considered inert and static. This is where the second revolution comes into play, and where I will begin to outline some recent works of architects and researchers that have started to prove that this revolution has longevity, legibility and validity in architecture.

The discipline has a now well-established interest in industrial digital fabrication technologies of production, such as CNC milling, 3D printing, laser cutting and robotic fabrication, amongst others. Although these are interlinked yet remained outside the direct realm of operation of most architects in late 20th century, they do have a clear history within architecture (one has only to look at Sigfried Giedion's *Mechanisation Takes Command* **from 1948 to see that this is the case). However, only in recent years have these technologies become a means of developing an approach to materiality that takes into account heterogeneity, difference and variability as tools for dismantling the dominant paradigms of** *imposing* **or** *equalising* **germane to materialist practices. The first comrades of this particular revolution were radicals within the practice or relevant institutions, but today it is rare in many parts of the world to find a school of architecture that does not have a digital fabrication workshop. Additive and subtractive processes of manufacturing, when utilised alongside digital simulation software and OOD, enable Evans's reading of the relationship between drawing and building to come back into the discussion. While OOD has shifted the architect away from the drawing and towards the building, in doing so it has revolutionised the translation of the work of architects to the construction industry. The introduction of digital fabrication methods has meant that architects can now ask of material, with Louis Kahn, what it wants to be, rather than imposing upon it a prescribed outcome. The three-dimensional model can become part of a feedback loop between physical material behaviour, digital simulation, and desired outcomes – taking into account that the space between the model and construction allows space for design ingenuity and opportunity, as well as constructive, productive and meaningful failure. Effectively, this means that architects can consider the emergent behaviours of material. Returning to Kahn's use of brick, what this kind of material practice allows in architecture is dissociation**

[5] *The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007-2012)*, McGraw Hill Construction, 2012.

from the notion that a material's purposiveness lies in its homogeneous application to an architectural object (building).

2. Discovering what material wants to be

Looking briefly at the following five projects, the aim ultimately is not to provide a concise definition of the meaning of materiality today; rather, it is to demonstrate the range of interpretations and methods used. We first look at a series of projects developed by students, each of which has attempted to exploit the potential of the material systems they are working with from very different perspectives – one in terms of how to achieve seamless casting through hacking into 3D printing and the other by exploring evolutionary computation in terms of how parameters and evolutionary algorithms can define material behaviour. The project which will act as the main feature for this paper is an open-source application we have developed called SoftModelling, drawing from democratic evolutions in computer science on the accessibility of code and an interest in engineered material practices. The final project included in this paper is the MArch final project of recently graduated Bartlett MArch GAD students Nan Jiang, Yiwei Wang, Zheeshan Ahmed and Yichao Chen (taught by Gilles Retsin and Jiménez Garcia) titled *Space Wires* looked at how to optimise, in real-time a structural heterogenous three-dimensional space frame, utilising robotic fabrication.

The methodology in our design studio the MArch Architecture programme at the Bartlett School of Architecture at UCL has a specific interest in the utilisation of analogue and computational material research into elastic membrane-based systems as well as adaptable and kinetic structures. Analogue material fabrication processes such as casting are combined with flexible synthetic materials such as silicon and latex. Additionally, latex and other synthetic plastics have been materials we have used in advanced fabrication techniques such as 3D printing – which have allowed our students to 3D print structural, as well as what could be used as mechanical systems, within the cast material. We have been able to quickly produce and test a variety of structural lattices that work within the same logic, casting membranes within, around or through these structural lattices. In terms of mechanical systems for water, heat, and electrical organisations, students in our design studio such as Tomas Tvarijonas have established ongoing research projects into the uses for dissolvable 3D printed plastics which are then cast in silicone or latex (Figure 1). Once cured, the 3D print is dissolved in water, leaving behind tubular lattice membranes within the cast, allowing for the possible insertion of structural carbon fibre tubing, water pipes and electric conduit (Figure 2 and 3). Furthermore, these kind of methods allows for structure and services to be built into the architectural system the ability for a single 'unit' or 'capsule' to become capable of being differentiated within the system, therefore enabling the same logic to be utilised for different kinds of architectural uses and functions. This

creates an architecture which is explicit in its demonstration of its flexibility in terms of materiality, structure as well as different programmatic and spatial complexities.

In addition, research has been done in designing adaptable mechanical structural frameworks which achieve similar aims but using more digital forms of computation rather than analogue computation as achieved in the previous project. The work featured here by Shuo Zhang specifically aimed to achieve the ability for an inflatable membrane to have enough programmatic, structural and geometric intelligence embedded within it to be able to be multi-performative. This of course has a very similar aim to Tvarijonas' work. However, Zhang's approach was through utilising evolutionary models of computation, building up a set of parameters early on in the work that were then run through an evolutionary algorithm in order to find optimal relationships between different parameters – including the relationship between structure and material. The research specifically focused on mechanisms that when hybridised with inflatable membranes and inflated, can become rigidified and used structurally, or when inflated, can mechanically connect to additional 'units' and combine utilising this same logic (Figure 4).

3. Seamless modelling of the 'thing' itself

Moving on to the third work addressed in this essay, we see Frei Otto's experiments with catenary structures and varied material systems (bubbles, string, etc.) as a precedent for this work, as well as the research into the material behaviour of concrete catenary systems by Antoni Gaudí. Many of today's digital modelling software packages emulate the analogue processes these two architects and engineers worked with. However, as the use of physical digital simulation in architecture has exponentially increased in the last decade, new challenges of utilising these tools have arisen. Contemporary advanced simulation software allows for a more accurate understanding of material behaviour at an architectural scale, and also works as a form-finding method. The potential of continual structural evaluation in form-finding allows for the morphology of an architectural system to be informed by physical laws instead of mathematical definitions in real-time, enabling the evaluation of multiple iterations of the same system to happen simultaneously. Despite the ever-increasing presence of OOD tools in architectural design practice, there have been few attempts to rethink the more common digital design tools that architects utilise today.

The application that we have been developing, called SoftModelling, interrogates the way in which we utilise these tools, with a particular interest in how to incorporate concepts drawn from open-source models of computing and production into the software tools that architects use daily. These more generic software packages, which are heavily licensed and regulated, have thus far limited the development of open-source tools in architectural design research largely to problem-solving linked to specific architectural projects. SoftModelling, on the other hand, is an open-source Java application developed to address not only a specific project; it can also cover the basic function of a digital design software,

as its code is open-source and easy to manipulate in order to create multiple versions by using Processing as a framework. It is multi-scalar in its application, as it connects together two of the most used design tools: poly-modelling and physical simulation (Figure 5). SoftModelling functions differently to other software packages available, tying together materiality and modelling into one digital feedback loop. To give an example, when modelling in Maya, the designer has to convert the model into a physical simulation, but cannot operate directly on the model when it is in the physical simulation. Kangaroo for Grasshopper works similarly, as you have to model the architectural object and then run the simulation, and so on. We improve on this problem with SoftModelling, by seamlessly integrating modelling and physics.

Most kinds of modelling software re-compute the order of edges when any mesh operation is given. This is why a two-step process is normally utilised, since the serial numbers of the particle-springs will not match the new edges' serial numbers after this operation takes place. SoftModelling develops a strategy for each of the mesh operations in order to solve this. First, the app relocates the serial numbers of each edge on the mesh to maintain parity between the particle-springs linked to them. Then, instead of a recompilation of the particle-spring system, a detailed analysis of the mesh identifies the parts that have been modified, without affecting the rest of the object. This process not only improves the efficiency of the physics simulation but facilitates a seamless integration of modelling and simulation. The synchronisation of particles – vertices/springs to edges – enables the constant updating of the positions of each part of the model. What one models is automatically physics, and vice versa. There is a continuous feedback between the physical behaviour of every particle-spring of the three-dimensional mesh subdivision and the variable scale and depth at every point, which leads to an output that is both physically and geometrically precise. This improves flexibility for the designer, as one can modify and simulate simultaneously with a single software, as well as edit the GUI and the interface. It establishes an understanding that particle-spring systems can not only be used as a global framework, but as a step-by-step transformative process for architectural design. This potentially could be used to create a three-dimensional pattern that has been physically evaluated and therefore could be 'unrolled' and automatically fabricated using digital fabrication technologies, thereby dramatically increasing the accuracy of predicted material behaviour through digital fabrication, in terms of structure and geometry (Figure 6).

4. Material extrusion and robotic fabrication

The recent project by Nan Jiang, Yiwei Wang, Zheeshan Ahmed and Yichao Chen who call themselves Filametrics and their project name *Space Wires*, from the MArch GAD Research Cluster 4 again at the Bartlett School of Architecture takes a somewhat different approach, but utilises many of the concepts outlined above, including building open source applications in order to more closely marry structure and geometry with construction and

fabrication technologies. This is no coincidence, as they were taught by Jiménez Garcia and Gilles Retsin at the Bartlett. The research cluster has a particular interest in the appropriation of 3D printing and robotic fabrication technologies for multi-hierarchical and multi-material architectural design strategies. The aim in the research cluster has been to discover material and fabrication anomalies in normative uses of both 3D printing and robotics, as well as traditional uses for materials such as concrete, clay and plastics, and utilise these anomalies as opportunities for architectural innovation. This project is one of four completed in the autumn of 2014, and focused on the use of filament plastics (Figure 7). The work is within the realm of the work on contour crafting by Behrokh Khoshnevis of University of Southern California, D-Shape by Enrico Dini, Mataerial by researchers Petr Novikov and Saša Jokić from Barcelona's Institute for Advanced Architecture of Catalonia (IAAC) at Joris Laarman Lab and Chairs for Charity by Dirk Vander Kooij. Through the invention of new technologies for robotic 3D plastic filament extrusion – such as printing heads for materials that can have the potential for multiple extrusion geometries, for example – the research has been able to achieve heterogeneity both in terms of structural complexity and spatial complexity in both robotic fabrication and digital computation, revolutionising the way in which architects can conceptualise the potential and limitations of space-frame lattices.

Where the group is most innovative is in their combination of two observations: one that space-frame lattices bear loads much greater than their own self-weight and secondly, that traditional 3D printing technologies waste a lot of material; oftentimes, much more waste is produced than utilised. They therefore utilise agent-based systems in combination with robotic plastic filament extrusion to generate structural data in real-time, mimicking the geometric patterns of a space-frame lattice structure. The structural data and resultant behaviour of material is analysed in real-time (Figure 8). Any anomalies, mistakes or failures that occurred in the output of the material system was fed back into the digital model, allowing for the output to be continuously updated in real-time. This kind of system could potentially revolutionise construction techniques due to its ability to adjust to changes in tolerance due to site conditions such as weather, soil composition, or the inaccuracy of the machine itself. It is also capable of achieving multi-hierarchical resolution of surfaces utilising the same system but slightly modifying its printing pattern, the viscosity of the material being printed and the path of the robotic printing head.

5. Conclusion

Each of the projects described above, while varied in the exact scope and scale of their material practice, attempt to bring together more closely the design process to construction through the utilisation of digital tools and fabrication technologies originally from outside the discipline of architecture. The object-orientated nature of this work means

that the properties of *the thing itself* take a place of prominence in each of these works. They aim ultimately to improve accessibility, increasing and acknowledging that heterogeneity and efficiency in production and fabrication, both in terms of cost and labour, allow architects to achieve a much greater specificity in the use of materials in design research. Heterogeneity is achieved not through what philosopher Manuel De Landa has recognised as the "spontaneous generation of form", but through topological difference and variability, best expressed by "complex and variable behaviour [of materials]".[6] What De Landa goes on to note is that this can result in continuous variation, where variation in densities of material can result in a material performance that is heterogeneous; acknowledging that a "single universal material is [not] good for all different kinds of structure."[7] When materiality is considered as continuous variation – i.e., when it is understood to be dynamic, fluxing, with emergent and plastic material behaviours – its conceptualisation and resultant instrumentalisation becomes the contemporary version of iterations of pencil on trace paper. Innovation occurs not in the translation between the two-dimensional drawing and building, but in the space between feedback amongst digital tools, fabrication systems and computational methods of architectural design research.

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Captions

Figure 1, 3D printed mould for latex casting, Tomas Tvarijonas

Figure 2, Seamless 3D printed and latex-casted piece, Tomas Tvarijonas

Figure 3, Seamless latex structural lattice, Tomas Tvarijonas

Figure 4, Computing mechanical and material parameters, Shuo Zhang

Figure 5, SoftModelling application interface, beta version 2.0

Figure 6, SoftModelling object catalogue

Figure 7, Render of material deposition, *Space Wires* by Filametrics

Figure 8, Material computation testing, *Space Wires* by Filametrics

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[6] De Landa, Manuel. "Uniformity and Variability: An Essay in the Philosopher of Matter", in *Digital Tectonics* (ed. Neil Leach, C. Turnbull, C. Williams), John Wiley & Sons: 2004, p 19-20, brackets added by author.
[7] Ibid.