Digital Master Builder: From 'Virtual' Conception to 'Actual' Production through Information Models

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Abstract. *This paper investigates relationships between the process of conception and production in digital domain with reference to the very nature of architect's profession. Authors combine some theories of actual paradigm shift with specific mechanisms of digital fabrication. A scope of control and collaboration strategies will be cited and a few next will be developed as an aftermath of the FABRICATE 2011 conference and publication. These remarks can be seen as an attempt to outline essential design principles for digital master builder architects.*
Keywords. *Digital paradigm; information models; CAD-CAM; digital fabrication.*

INTRODUCTION

In recent years a powerful outfit was given to architects. It is the outfit of digital fabrication technologies that allow to quickly convert digital ideas into real entities. It also enables automated fabrication of full-scale building components directly from digital information models. The advent of digitally controlled fabrication means that the architect is as close to the materialization as in the original craft process. Furthermore, he gained the precision, control and the ability to explore complexity which was previously impossible. As the available tools become more sophisticated, it must be considered that the role of such tools is not only to make working methods more efficient, but to contribute to the idea of architectural creation.

"Over the past decade, key relationships between design and making have been thoroughly redefined by integrated and automated digital technologies" (Glynn and Sheil, 2011). Computer aided design and manufacturing processes enabled a direct translation of virtual creations into physical artifacts and therefore have attracted the interest of many architects. Integration of the design, analysis, manufacture and assembly of buildings around digital technologies reveals the opportunity to fundamentally redefine the relationships between conception and production in architecture.

ARCHITECT MEANS BUILDER

Etymologically, 'architect' derives from the Latin *architectus*, what itself derived from the Greek *arkhitekton* where *arkhi-* stands for 'chief' and *-tekton* stands for 'builder'. From the very beginning, being an architect meant being a builder. The understanding of the essence of architecture by the ancients was distinctive. For Vitruvius, it was the work, in which the artistry, skills and knowledge of an architect was expressed. A wide range of knowledge required from an architect briefly summarized the division for a practical knowledge (*fabrica*) and theoretical knowledge (*ratiocinatio*). Through centuries, from Ancient to Middle Ages, master builders were in charge of all aspects of buildings. Simulated by the cultural transformations in the history of civilization, architectural activity has always been defined by the relationship between art and technology, ultimately materialized in forms of physical buildings. Architects were closely involved in both the shaping of the space and the construction process. Strong intentions for creating physical structures simply rest in the architect's nature. The progressing integration of the conception and production phase under digital tools can satisfy this primary desire.

PARADIGMS IN ARCHITECTURE

Since architecture has emerged as an autonomous field of human activity, we marked the characteristic forms of paradigms, which define the correlation between conceptual ideas – models – and their materialization in the form of buildings. In the history of architecture, Renaissance was the turning point in crystallization of the discipline's autonomy and obligatory paradigms at the same time. Leon Battista Alberti, in his *Ten Books on Architecture,* insisted that architecture should be independent from the structure. Hence, this led to the separation of the artists and architects from the builders and craftsmen. Through his theories, Alberti became an advocate of architects engaged in design but not in construction (Garber 2009b). This model of relationships between the 'annotated' and 'built' architecture, turned out to be a symptom of a process leading to the deeper stratification in the field of architecture. It caused extreme effects of two opposite phenomena, building architecture without an architect on the one hand, and creation of annotated architecture deprived from its materialized condition on the other hand. Paradoxically, it was the Industrial Revolution that seemed to pave the way of a real split between annotated architecture and its physical constructing. Some intellectual efforts spectacularly reflected in the treaties of John Ruskin could be seen as a reaction for a prospective threat of repetitive architecture from 'spiritless machines'. With many of his utopian demands, Ruskin's thoughts proved to be a creative impulse towards a return to architectural values, which integrate elements of original ideas, reliable design and craftsmanship. Echoes of those aesthetical and moral paradigms of John Ruskin certainly sounded in manifestos of Chicago School or modern Bauhaus. The doctrine of modernism, freed from the historical ballast, inspired a fresh approach to architecture and became a new area for solving current social, technical and aesthetic problems. Regardless of the number of significant reevaluations of the Modernism, contemporary digital architecture remains a cultural phenomenon, in which architects intensify the relationship between the process of conceiving and constructing of buildings.

DIGITAL PARADIGM

Over the past two decades, the use of computers in architectural design has allowed architects to better estimate their intentions virtually and gain a far greater degree of control over the design. New digital protocols and techniques give the opportunities to move away from traditional methods of conceiving and constructing buildings.

Some writers see this as a paradigm shift in the design and production process. It can be described as the move from the old paradigm of 'the possible to the real' to a new one, 'the virtual to the actual' (Garber and Jabi, 2006) [Figure 1]. According to Stanford Kwinter (2001): "What is most important to understand here is that unlike in the previous schema where the 'possible' had no reality (before emerging), here the virtual, though it may yet have no actuality, is nonetheless already fully real." Manuel DeLanda (2002) intensified this even more, deliberating the use of digital modeling software and its ability to reconfigure the design process itself. 'The possible to the real' paradigm is initiated with the creation of an immaterial form which then has a material substrate later applied to it. In 'the virtual to the actual' paradigm the virtual construct already has embedded some information including materiality, weight or assembly process.

Digital architects do not prepare a two-dimensional hard copy set of documents anymore to represent a possible building. They develop precise virtual construct that is actualized through translation to another medium. The process of translation has replaced the process of interpretation in the former paradigm. From the very start three-dimensional forms exist in a computational three-dimensional space where all geometrical points are a set of three coordinates that locate each point. As a result, a coherent object, is automatically measured and build informationally – and computers can actually fabricate the same object for good via a suitable CNC machinery (Carpo 2011). Owing to CAD-CAM integration, design and production is merged and overlapped in a single, seamless process of creation and production. This could be seen as a manifestation of rejecting the Albertian Paradigm which claims that architects should not make things but should just design and annotate them. Today, in many cases, existing CAD-CAM technologies have already achieved that stage: an architect's design can be immediately and automatically fabricated – if need be, in front of the architect and while the architect is still working on it (Carpo 2011). Present CAD-CAM technologies, often seen as a part of the Building Information Modeling (BIM), have already started to bridge the gap between design and fabrication in architecture.

FABRICATE 2011

FABRICATE 2011 was an International Peer Reviewed Conference, Publication and Exhibition hosted by the Bartlett School of Architecture and held on 15-16 of April 2011 in London. It brought together pioneers in design and making within architecture, construction, engineering, manufacturing, material technology and computation. FABRICATE 2011 served an unusual opportunity to explore the world's most recent approaches by discussing the progressive integration of digital design with manufacturing processes. This event was a great chance to see how digital technologies impact on design and making in the 21st century.

All projects submitted to the conference could be divided in two main categories, what has been reflected in the *FABRICATE: Making Digital Architecture* publication. The first section of this book contains case studies from multi-institutional programs, departmental research groups, doctoral candidates, design units and individual graduates. Much of this work could be called a proto-architectural and came from renowned institutions such as Delft, Harvard, MIT, The Bartlett, CITA, and London's Architectural Association. The second section contains works coming from world-known architectural practices and engineering firms including Foster+Partners, Zaha Hadid Architects, Arup, Buro Happold, Amanda Levette Architects, Ron Arad Associates. The rich content of the conference was constituted by 31 case studies covering a cross section of scales and typologies.

FABRICATE conference was an excellent opportunity to track the latest developments in the domain of

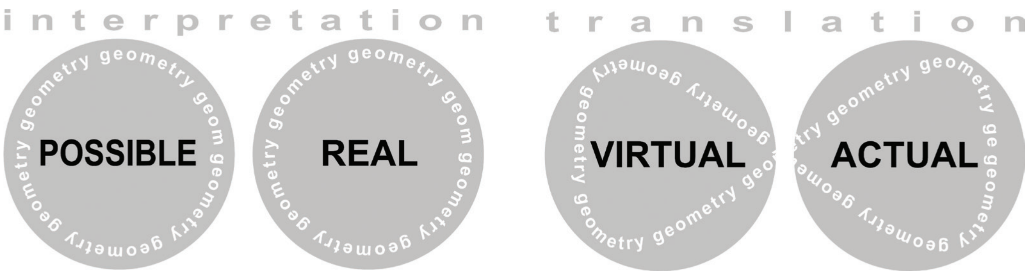

Figure 1
Diagram showing the old paradigm versus the new paradigm.

digital fabrication. Therefore, this London's event was treated as an exceptional case study to illustrate not only the most recent developments in the application of computational techniques in design and making, but also the shifting paradigms of contemporary architecture. Examples presented at The Barlett, together with views advocated by the keynote speakers led to some general observations, which will partially constitute components of an ongoing PhD dissertation conducted at the Faculty of Architecture, Silesian University of Technology. Two particularly interesting aspects were noted. The first problem describes the importance of information and particularly the use of information models in architectural practice. The second aspect concerns the imperishable importance of a geometry in the process of transferring the design intent to physical structure.

INFORMATION FLOW

Information is in the center of collaboration, coordination and communication in architecture. It has expanded beyond representation-based documentation that drives the construction phase (Szalapaj 2005). Design computing continually develops itself for more aspects like analysis, simulation and material performance (Kalay 2004). These new components allow architects to better understand and manage how their virtual ideas are realized, and to innovate or challenge traditional construction methods. The synthesis of such technologies has led to the emergence of building information models which promise to revolutionize contemporary design practice (Garber 2009a).

Digital technologies have fostered an integrated and collaborative relationship between the process of design and the act of making. Digital files carry information of all the parts which would be transferred from computer to robotic machinery (Picon 2003). Today, design and making can be a simultaneous process based on the exchange of information between design and fabrication in a rapid flow of data (Glynn and Sheil, 2011). According to Mario Campo (2011) this way of operating evokes somehow an ideal state of original, autographical, artisanal hand-making, except that in a digitalized production chain the primary object of design is now an informational model.

ESSENTIAL GEOMETRY

Three-dimensional geometry is the core of the process of converting virtual geometries into physical materials. In many cases architects use various parametric and generative techniques to build digital 'master' geometries. These master models become a sole of information for fabrication processes (Villalon and Lobel, 2007).

With regard to fabrication, design information embedded in the digital geometry must be operated according to specific, machine dependent guidelines. Since, every fabrication machine typically has its own characteristics, that logic had to be put into the geometry model. The designer must think about the design elements they wish to create according to specific machinery they want to use (Villalon and Lobel, 2007). A lot of parametric and constraint-based logics is used in order to create models which were then translated into machine-ready formats, fabricated and assembled (Schodek 2005). This geometric rigor is deployed to integrate manufacturing constraints, assembly logics and material characteristics in the fabrication.

The geometry still represents the core of the architectural design process. It plays an essential role from conception to production of physical elements (Stavric and Marina, 2011). Through precision in creation of digital models and control over their translation, buildings can be more consistent with the architect's original intention. Digital fabrication workflows exhibited during the FABRICATE 2011 coincide with control and collaboration strategies described by Richard Garber and Wassim Jabi (2006). These six strategies below are still particularly important in the context of providing proper design information by digital architects.

- Geometry is created as a shared 3D virtual as opposed to a set of annotated drawings.

- Geometry is rule-based and parametrically constrained, so as to encode materials and assembly methods.
- Geometry is linked to an integrated database, so as to enhance collaboration.
- Geometry is rationalized, segmented, and ordered for physical assembly.
- Geometry is sent directly to Computer Numerically Controlled (CNC) hardware for manufacturing.
- Geometry is translated and transferred digitally, thus avoiding interpretation errors.

SELECTED CASE STUDIES

Many of the FBARICATE 2011 case studies revealed successive digital fabrication strategies. Many of the demonstrated projects could illustrate not only one or two strategies but they could mirror several of them. It also appeared that some of the strategies have become common daily routines for digital designers. Therefore, an attempt to formulate new problems relating to the geometry was made. Strategies listed below were derived from the 5 selected and most influencing projects discussed during the conference [Figure 2].

1. Geometry is prepared to explore material behavior and to support feedback from the physical structure.
2. Geometry is generated to explore performance logic rather than formal intent.
3. Geometry is built as an exact hardware's tool path to embed fabrication logic.
4. Geometry is shared across different platforms and file formats as a coherent set of information.
5. Geometry is translated into physical artifacts in a nonlinear, many stepped process.

Research Pavilion by the ICD/ITKE (1)

A temporary research pavilion was designed, fabricated and constructed at the University of Stuttgart. This example presents one strategy of

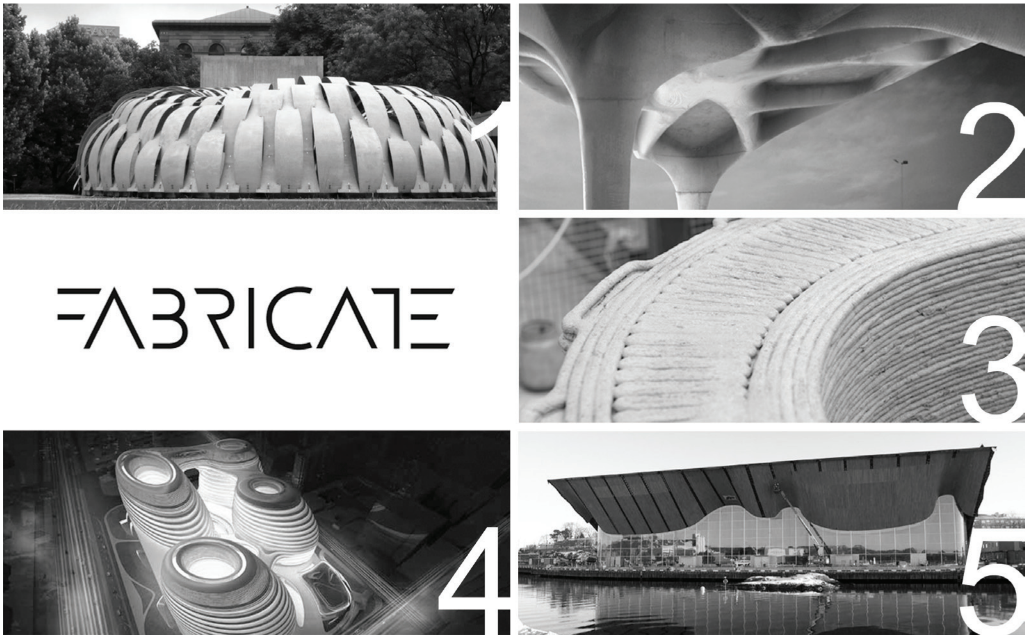

Figure 2
Five selected Fabricate 2011 case studies illustrating five digital fabrication strategies (source: [1],[2],[3],[4],[5])

material-oriented computational design where structure and space is informed by the physical behavior of bent plywood and the constraints of the fabrication tools (Menges, Schleicher and Fleischmann, 2011). Three models were used to develop this project: the computational design model, the FEM model derived by structural engineers, the actual model measured by geodesic engineers. The project's coordination and mediating was done through the design model. In this model relevant material behavioral features were embedded in the form of geometric relationships captured into parametric principles. The computational generated geometry was directly driven and informed by physical behavior and material characteristics as well as by the fabrication constraints of the employed industrial robot (Menges, Schleicher and Fleischmann, 2011). This project reveled geometrical complexity and performance capacity without differentiating between virtual form generation and physical materialization processes.

Unikabeton Prototype at the Aarhus School of Architecture (2)

This project was a final result of the cross-disciplinary research project exploring topology optimization with robotic fabrication of concrete casting molds (Søndergaard and Dombernowsky, 2011). This prototype challenged the scheme for the optimization of a non-uniform doubly-curved concrete slab supported by three asymmetrically placed concrete columns. A minimal surface form-finding software was used to generate the design space for the slab. In next few steps the geometry of the slab was topologically optimized for overall structural loads. The optimization output was generated to meet the fabrication requirements of the one-sided CNC milling process. The result of the optimization process was then remodeled in Rhino to prepare the surface for milling. Eventually, an inverted negative geometry was directly milled in polystyrene blocks. The Unikabeton Prototype revealed the potential of a new language of geometric form specific to the computational logic where maximum of structural performance is generated by the smallest possible means (Søndergaard and Dombernowsky, 2011).

Free-Form Construction Project at the Loughborough University (3)

This project illustrated the design and construction of an additive fabricated wall component. It was a part of a wider research on digital design environments for additive fabrication (De Kestelier 2011). A prototype of a wall component was printed on the concrete printer to demonstrate its current capabilities. Within this technology the concrete is deposited without the use of any formwork what introduces a lot of freedom in geometrical complexity. Traditional methods of modeling, even parametric modeling, was not sufficient in this case. Therefore, a parametric model was set up in Generative Components. Designers had to define the shape of the wall as well as the actual tool path as the same time. The manufacturing process became an integral part of the design. There was no intermediate step needed to go from 3D model to a set of fabrication instructions. The geometry and the design process had the fabrication technology embedded in it.

Galaxy SOHO by Zaha Hadid Architects (4)

The Galaxy SOHO Project is a commercial mixed-use development currently under construction in Beijing, China. This large scale project can be considered representative of the digital design, coordination, documentation and fabrication techniques currently being developed by a prestigious architectural practice (Ceccato 2011). The conceptual phase of the design was developed using Maya software. The master surface geometry formed the basis for a 3D digital coordination process using CATIA/Digital Project. The 3D model was used in all conventional BIM processes including geometry development, digital coordination, clash detection and drawing production (Ceccato 2011). It was also used as an instrument of contract and according geometric authority of the facade system. The facade geometry was developed in few steps of rationalization and optimization, all based on parametric definitions. This example illustrates the design, geometric development, fabrication and construction of a complex cladding system which geometry was shared as a coherent set of information.

Waved Wooden Wall by designtoproduction (5)

The Kilden Performing Arts Centre in Kristiansand (Norway) was designed by ALA Architects. The most interesting part of this building is a timber wall defining the water front facade. designtoproduction in close cooperation with timber specialists developed a pre-fabrication and assembly concept for this facade. The geometry of the wall was prepared as a parametric model in Rhino, using RhinoScript and some extensions written in Microsoft.NET. It was defined by a ruled surface between a straight line at the top and a curved line at the bottom. In order to meet specific requirements, a surface with all generatrices having parallel XY-projections was generated. The parametric model was used directly to export the production data for all timber components. The facade was carried out in a step-by-step approach where a tangible geometry was a result of every automated procedure (Stehling and Scheurer, 2011). This geometry was then validated and punctually adjusted before continuing. This system was flexible and allowed designers to decide whether to repeat any automated step or resolve it manually (Stehling and Scheurer, 2011). The parametric system consisted of a set of specialized tools applied one after another to ensure the flexibility and pragmatism of a real-world project.

DIGITAL MASTER BUILDER PRINCIPLES

Digital fabrication brings the potential to put the designer once again in direct control of the craft of material shaping and construction. The quest for responsibility provides a necessary outline for the development of new principles in the realization of a design into physical architecture. As architects and designers become more familiar with available means and methods of digital fabrication, they will be able to better collaborate, coordinate and communicate with fabricators and manufacturers. They will not have to seek assistance of intermediaries in order to translate their design information into a fabrication-ready format. They will simply control data that ultimately drives the fabrication equipment on their own.

The new distribution of roles between making and designing calls for the development of a new set of design principles. All the strategies described earlier underline the importance of a digital model, free of representational annotation, which is used to transfer ideas into real. These strategies connect software with hardware, they organize and translate data from virtual to physical environment. They help architects to maintain control of original design intentions. Finally, they could be proposed as principles for a digital master builder architect.

CONCLUSIONS

- The historic links between architecture and its means of production are increasingly being challenged by the emerging of digital fabrication The architect, like his medieval forbears, becomes far more directly involved in issues of fabrication and construction and the interactive relationship between practitioner and material (Kolarevic 2003). In the Albertian paradigm interpretation was necessary to mediate between the architect's intention and the realization of the building – a possible to real relationship that could not ensure precision in the translation from drawing to building. In the information model the ability to translate and actualize data from the virtual state is embedded. In other words, one could say that information geometry is both virtual and actual at the same time to ensure the translation of designer's ideas into materialized world.
- Due to CAD-CAM integration digital architects today are increasingly designing and making at the same time. Mario Carpo (2011) writes: "Acting almost like prosthetic extensions of the hands of the artisan, digital design and fabrica-

tion tools are creating a curiously high-tech analog of preindustrial artisanal practices". Digital designers similar to traditional craftsmen make with their tools what they have in their minds. The very essence of making digital architecture embraces the translation of a geometry from the virtual to the actual state.

- The process of making buildings, stimulated by the digital paradigm, verifies the domain of an architect. The scope of new abilities to pursue architecture is developed. The position of an architect as an independent, visionary creator is being replaced by the position of a leader in egalitarian team of experts. This new leadership introduces the issue of architects' liability and displays itself in providing, understanding and handling of a master geometry.
- Computing in architecture "brings the ability to control fabrication digitally, to drive cutting, bending and assembling, to simulate and optimize material performance, to control geometry with precision" (Penn 2011). Digital fabrication tools simply place more control and responsibility into hands of contemporary architects. These advances represent an opportunity for architects to relocate themselves within the space of the construction industry, back in the heart of the process. A digital master builder architect should deeply understand relationships between the tool, material and form. Providing the exact geometry, which is the core of information flow in architecture, truly exhibits designer's consciousness. The ultimate transition from virtual intents to actual artifacts happens through exchange of geometrical information with fabrication logics embedded in it. According to Matthias Kohler (Glynn and Sheil, 2011) "in the near future, more and more information will be provided very explicitly by architects". This is particularly important since this information will be transmitted to machines that actually build from this data with no other person being responsible for its outcome.

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REFERENCES
Carpo, M 2008, 'Non standard morality: digital technology and its discontents', in A. Vidler (eds), *Architecture between spectacle and use*, Yale University Press, New Haven, pp. 127-142.

Carpo, M 2011, *The Alphabet and the Algorithm*, MIT Press, Cambridge.

Ceccato, C 2011, 'Galaxy SOHO' in R. Glynn and B. Sheil (eds), *Fabricate: Making Digital Architecture*, Riverside Architectural Press, Cambridge, Ontario, pp. 168-175.

DeLanda, M 2002, 'Philosophies of Design: The Case of Modeling Software', in *Verb Processing: Architecture Boogazine,* Actar Press, Barcelona, pp. 139.

De Kestelier, X 2011, 'Design Potential for Large-Scale Additive Fabrication' in R. Glynn and B. Sheil (eds), *Fabricate: Making Digital Architecture*, Riverside Architectural Press, Cambridge, Ontario, pp. 244-249.

Garber, R 2009a, 'Optimization Stories: The Impact of Building Information Modeling on Contemporary Design Practice', *AD Closing the Gap,* 79(2), pp. 6-13.

Garber, R 2009b, 'Alberti's Paradigm', *AD Closing the Gap*, 79(2), pp. 88-93.

Garber, R and Jabi, W 2006, 'Control and collaboration: digital fabrication strategies in academia and practice', *International Journal of Architectural Computing,* 4(2), pp. 121-143.

Glynn, R and Sheil, B (eds) 2011, *Fabricate: Making Digital Architecture,* Riverside Architectural Press, Cambridge, Ontario.

Kalay, Y 2004, *Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design,* MIT Press, Cambridge.

Kolarevic, B (eds) 2003, A*rchitecture in the Digital Age: Design and Manufacturing,* Spon Press Taylor & Francis Group, New York & London.

Menges, A, Schleicher, S and Fleischmann, M 2011, '*Research Pavilion*, ICD/ITKE' in R. Glynn and B. Sheil (eds), F*abricate: Making Digital Architecture*, Riverside Architectural Press, Cambridge, Ontario, pp. 22-27.

Penn, A 2011, 'Foreword' in R. Glynn and B. Sheil (eds), *Fabricate: Making Digital Architecture, Riverside* Architectural Press, Cambridge, Ontario, pp. 12-13.

Picon, A 2003, 'Architecture, Science, Technology, and the Virtual Realm' in A. Picon and A. Ponte, *Architecture and the Sciences: Exchanging Metaphors, Princeton Architectural* Press, New York, pp. 296.

Schodek D (et al.) 2005, *Digital Design and Manufacturing: CAD/CAM Applications in Architecture and Design,* John Wiley & Sons, Hoboken, New Jersey.

Søndergaard, A and Dombernowsky, P 2011, 'Unikabeton Prototype' in R. Glynn and B. Sheil (eds), *Fabricate: Making Digital Architecture,* Riverside Architectural Press, Cambridge, Ontario, pp. 55-61.

Stavric, M and Marina, O 2011, 'Parametric Modeling for Advanced Architecture', *International Journal of Applied Mathematics and Informatics,* vol. 5, no. 1, pp. 9-16.

Stehling, H and Scheurer, F 2011, 'Waved Wooden Wall' in R. Glynn and B. Sheil (eds), F*abricate: Making Digital Architecture,* Riverside Architectural Press, Cambridge, Ontario, pp. 228-231.

Szalapaj, P 2005, *Contemporary Architecture and the Digital Design Process,* Architectural Press, Oxford.

Kwinter, S 2001, A*rchitectures of Time: Toward a Theory of the Event in Modernist Culture*, MIT Press, Cambridge.

Villalon, R and Lobel, J 2007, 'Materializing Design: Contemporary issues in the Use of CAD/CAM Technology in the Architectural Design and Fabrication Process', *Proceeding of the ASCAAD-07 Conference*, Alexandria, Egypt, pp. 317-326.

[1] http://icd.uni-stuttgart.de/?p=4458

[2] http://fluxstructures.net/

[3] http://www.fabricate2011.org/speaker-xavier-de-kestelier-of-foster-partners/

[4] http://www.zaha-hadid.com/offices-and-towers/galaxy-soho

[5] http://www.designtoproduction.ch/content/view/88