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Applied studies in Digital Fabrication and Parametricism

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Keywords: Digital Fabrication, Digital tectonics, CAD/CAM, Parametric Design

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Abstract

Presented is a research investigating the ability of digital fabrication tools to provide an alternative method for creating complex forms as part of an ongoing PhD research. The digital tool provides a comprehensive digital basis for construction that, since the beginning of building industrialization, has been an illusion rather than a reality. Beyond catching up on technology, the digital fabrication tool hereby provokes fundamental changes in the architectural discipline: the mere relation of the digital reality of computers with the physical reality of architecture. As opposed to the experiments in the early days of digitization, the focus is no longer on form, rather it is on the physical improvement of the discipline. This paper therefore presents a review of contemporary attempts within the time frame of the past four years with a thorough analysis and breakdown of the prototypes. In comparison to these examples, and considering the same building materials, another case studies are explored as precedents in history that have challenged the traditional understanding of the production of architectural forms. The understanding of the essential factors that constitute the advanced design process is consequently put into discussion. The relations between these factors and their direct effect over the architectural process has changed with the digitizing processes. This is also discussed and analyzed in regards to the implications and possibilities emerging for an indefinite relation between the tool and the design. The paper suggests a new medium linking the virtual and built environments and highlights the limitations of these new trends.

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Digital Fabrication, Digital tectonics, CAD/CAM, Parametric Design

APPLIED STUDIES IN DIGITAL FABRICATION AND PARAMETRICISM

RASHA SUKKARIEH[1]

ABSTRACT

Presented is a research investigating the ability of digital fabrication tools to provide an alternative method for creating complex forms as part of an ongoing PhD research. The digital tool provides a comprehensive digital basis for construction that, since the beginning of building industrialization, has been an illusion rather than a reality. Beyond catching up on technology, the digital fabrication tool hereby provokes fundamental changes in the architectural discipline: the mere relation of the digital reality of computers with the physical reality of architecture. As opposed to the experiments in the early days of digitization, the focus is no longer on form, rather it is on the physical improvement of the discipline. This paper therefore presents a review of contemporary attempts within the time frame of the past four years with a thorough analysis and breakdown of the prototypes. In comparison to these examples, and considering the same building materials, another case studies are explored as precedents in history that have challenged the traditional understanding of the production of architectural forms. The understanding of the essential factors that constitute the advanced design process is consequently put into discussion. The relations between these factors and their direct effect over the architectural process has changed with the digitizing processes. This is also discussed and analyzed in regards to the implications and possibilities emerging for an indefinite relation between the tool and the design. The paper suggests a new medium linking the virtual and built environments and highlights the limitations of these new trends.

KEYWORDS

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1. INTRODUCTION

Over the past thirty years there has been a commonly discussed involvement of digitally operated tools by creative disciplines. Seeking advancements in computational design and parametric modeling techniques, designers have found industrial fabrication tools as an ultimate development platform for their creations. While the manufacturing industries have improved the accuracy, flexibility and reliability of these digital tools, and while the accessibility to the technology for the new users has also increased given the emerging open standards and connectivity notions, designers have leveraged the flexibility of the fabrication technologies as an opportunity to reconfigure the complete design-production chain rather than remaining in the realm of deriving formal complexities.

After numerous attempts, architects have elaborated on the consequences of the digitization on the discipline, yet several have failed to unfold a redefinition of the design-build process. Meanwhile, the rise of personalization and individualism, mass customization has become vital in architecture. With the integration of parametric design tools and with the support of reliable digital fabrication technologies, a new model that is committed to address the design and construction processes through its technology with more customizable approach has emerged as a new paradigm.

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2. AIMS AND OBJECTIVES

The aim of this paper is to analyze the previous trials and built case studies of traditionally constructed structures in comparison to digitally fabricated ones, both sharing the same construction material. The purpose of this analysis is to understand the major factors affecting the contemporary design decisions and whether the necessity for these digital fabrication tools has been irreplaceable to meet a time and cost-efficient complex structures.

Therefore, this research aims to develop a workflow combined with material and construction constraints that has the potential to increase performance objectives while enabling geometric complexity and design driven articulation of a traditional tectonic system. The emphasis of the research is to take advantage of material properties and assembly methods applied to a digital design that enables emergent patterns to influence the performance of the space.

The paper also discusses within a comparative analysis of two specific case studies, the degree of success of the digital fabrication tools in providing adequate solutions for their intended purposes. The discussion is built upon the fundamentals of features related to material and time efficiency as well as innovation and cost.

3. MANUFACTURING OF BUILDING COMPONENTS

The selection of two case studies in this paper aims at displaying a characteristic sample that covers a range of digitally fabricated pioneering projects not only from a time-progression point of view but also highlighting the trends in the innovation of the construction methodology utilized. In parallel, two other case studies are explored as historical precedents that have challenged our traditional understanding of the production of architectural forms. The accelerated developments in technologies for design and fabrication are motivating a field of formal investigations that need to be brought into planned alignment with other disciplinary logics to demonstrate their true transformative capacity.

The first range of case studies where selected based on a pioneering built projects in the realm of digital fabrication in our recent times, where architectural advancements had been starting to develop extensively. The materiality has been considered as a second benchmark. The materials chosen are the most commonly used in the construction domain regarding facades, namely: ceramics, and brick. Hence, the third criterion considered shall be the digital tool itself, namely CNC milling machines and 6 or 8 axis robotic arm. Understanding the combination between the materiality and the tool eventually leads to formulating a categorization of the factors influencing the design process. In comparison to these recent case studies, precedents adopting similar formal challenges and building materials were considered and analyzed aiming to deduce the effect of the digital tools on the architectural process in general and the design-build relationship in particular.

3.1 Brick Facades

Case Study 1: Church of Cristo Obrero, Uruguay – *by Eladio Dieste (1952).*

In this project, the architect challenged the undulating brick walls based on the principle of increasing their structural performance. Each wall is 30 cm thick and rises to a height of 7 meters. The geometry of these facades was approached structurally through curving the surfaces in the longitudinal direction to avoid deflection. The height of the profile as the section moves from the center to both ends was reduced to accommodate a lighter structure which spans between 16 and 18 meters. Through the flexibility of the surface, the design process was turned into a problem of material logic regarding the articulation of structural performance, geometry, and form. Regarding the construction process, the church was completed in two years with a very low budget using traditional building techniques and with the aid of local workforce. Dieste’s particular approach to the design redefined ideas of materiality in architecture.

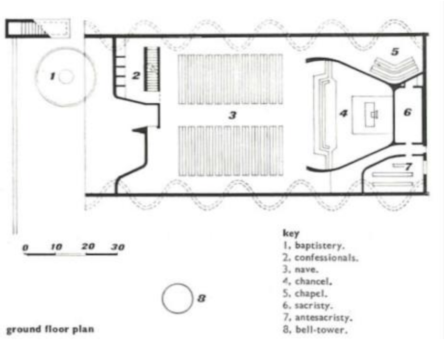


Fig. 1 Ground Floor Plan
Reference: Architecture League NY

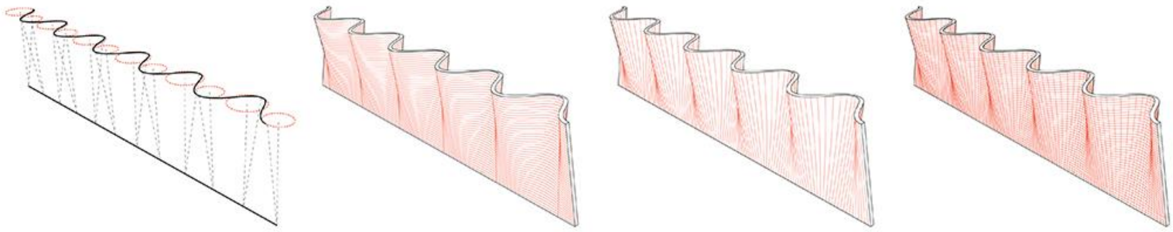


Fig 2. Diagram of Surface Generation, Reference: The Architectural League, NY

Case Study 2: Chi She Gallery, China – *by Archi-Union Architects (2016).*

This project aimed at reconstructing the facades of an existing concrete structure using brick. The brick walls therefore are considered structural yet act as a skin to the facade. The wrinkled wall texture was based on a parametric algorithm created to represents a dynamic architectural expressions by allocating the brick tiles along various curved paths. In order to complete such a masonry process that cannot be precisely achieved by traditional processes, the robotic masonry fabrication technique was applied. The external walls therefore were constructed with the help of the advanced technology of the robotic arm, which generates a staggered surface morphology. The precise positioning of the integrated equipment of robotic masonry fabrication technique and the construction by mortar and bricks make this ancient material, brick, able to meet the requirements in the new era. This advanced fabrication technique has allowed the construction process of these walls, spanning between 13x4 meters dimensions, to be finalized within 6 months with a relatively low budget.

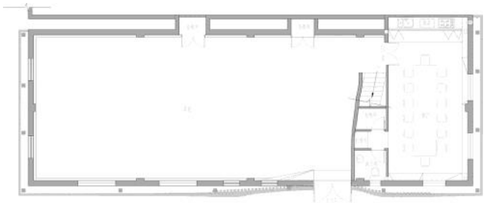


Fig. 3 Ground Floor Plan
Reference: Archi-Union Architects

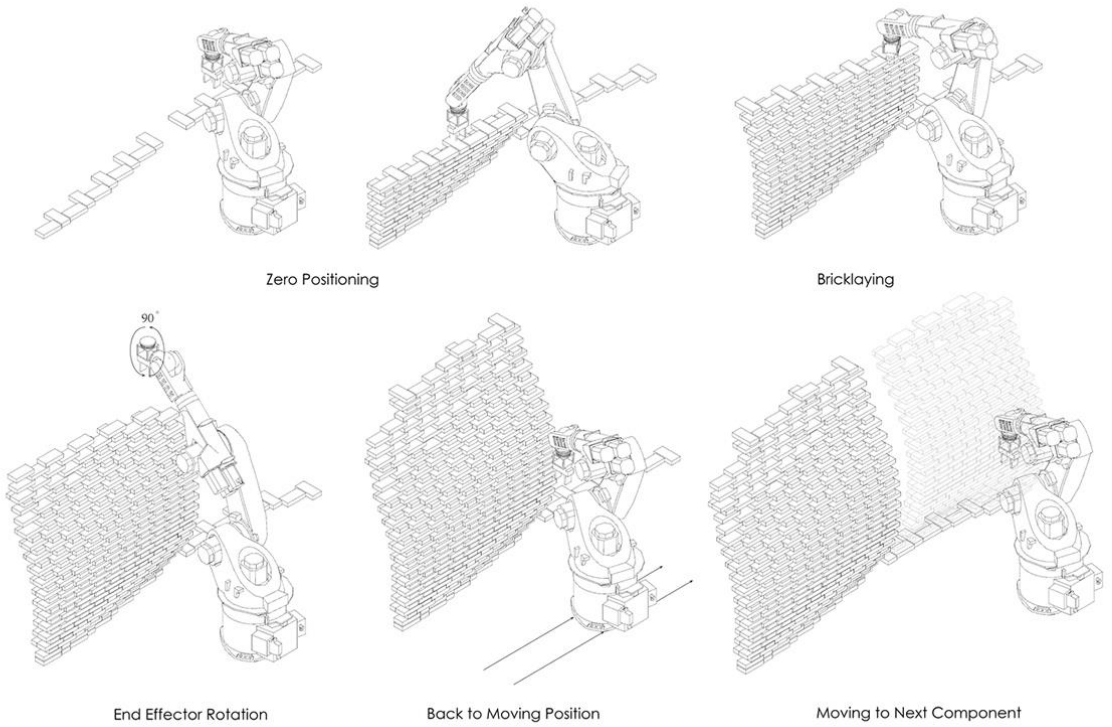


Fig 4. Construction Diagrams, Reference: Archi-Union Architects

3.2 Ceramic Tiling

Case Study 3: The Panot Tiles, Spain – *by Antonio Gaudi (1904).*

Fig. 5 The Panot ceramic tile Reference: Escofet

In 1904 Antoni Gaudí designed a model of hexagonal surface slabs containing three different elements identified as the three marine elements: starfish, algae and sea snails. Each piece included a third element and each one required a minimum of seven bricks to see the entire group. When Gaudi designed it, it had been intended for use in the Casa Batllo in Barcelona (Spain), but production problems hindered the solidification of the idea and instead was employed in another building of his. The dimensions of each tile was a format of 43 centimeters side. The fabrication process took a traditional path at the time (using metal molds). A problem in the design and the material characteristic was detected at a later stage when the pieces were broken very easily due to its large surface area. In this case, although the initial design was challenging, the fabrication process was long and costly and the possibility of modifying the design to meet the material capabilities was hard to achieve using the traditional process of producing ceramic tiles.

Case Study 4: Villa Nurbs, Spain – *by Cloud 9 Architects (2013).*

Villa Nurbs integrated art structures with ceramic, a material with a long tradition in architecture, both in the construction and finishing of buildings. The production of ceramics, intended for the north facade of the villa, was carried out by digital technology molds. Strategic customization was employed to create 3D ceramic elements through slump molding process. During production, a 600x25 millimeter extrusion was hand-cut to prescribed 2D shapes using water-jet aluminum patterns and then manually slumped over polystyrene molds which were digitally modelled and prepared using a 3 axis CNC milling machine. In total, 60 molds were created and reused to form parts in batches to achieve the final 460 elements that range in length from 500-1400 millimeters. The advantage of building between industrial production and craft-based fabrication made way to a more flexible and fast track fabrication process of a customized complex forms.

Fig. 6 The shaping of the ceramic tile
Reference: Cloud 9 Architects

4. DISCUSSION

Digital fabrication indicates a major shift in the way the new architectural era is visualized. The techniques used by digital fabrication requires to rethink the design process, often developing novel methodologies and nonlinear approaches by allowing integration and strategies of creative ideas and manufacturing operations to inform each other in a meaningful way, the potential of this movement may be fully realized. Key to this development is an interest in experimentation and therefore exploration of materiality and how design intent may be connected or expressed through their employment. The use of computational design to develop digital tools has been integral to mentioned recent case studies. Given that these tools provide interface between design and fabrication, the experimentation and customization afforded by them should offer a wealth of opportunities for researchers and architects.

In the two particular case studies of Chi She Gallery and Villa Nurbs, connecting digital design with digital manufacturing allowed the designers to understand material and fabrication characteristics in advance, through direct experiments, and eventually considered them in a generative way within the project development. The diffusion of the used advanced machinery (6 axis Robotic arm and CNC milling machine respectively) has outlined the synergy between digital and material processes in design and construction as a concept of emerging importance. This paradigm, defined as digital materiality, tolerated an interweaving of data and material, programming and construction as opposed to the traditional case studies, which, although implementing complex geometries, failed at the constructing phase to realize the design in an efficient time frame and taking into consideration the material properties. This is evident in the example of the brick where the thickness of the walls in Dieste's design was almost triple that used in the Chi She Gallery. As for the case of ceramics, although Gaudi's design was not relatively complex, the incomplete understanding of the material's characteristics has resulted firstly in the delay in the production and even the failure of the product due to the lack of experimentation preceding the final production phase as in the case of Villa Nurbs.

Consequently, in the cases of Chi She Gallery and Villa Nurbs, material is not just considered in terms of physical or aesthetic properties to enrich the conceptual design, but thoroughly explored and shaped by digital information. The idea of advanced customization, informed by the novel material awareness, suggests the potential development of a new paradigm of integrated architectural systems, overcoming the modernist tradition that classifies construction elements by pre-determined typologies of forms, structures and materials (Naboni and Paoletti 2015).

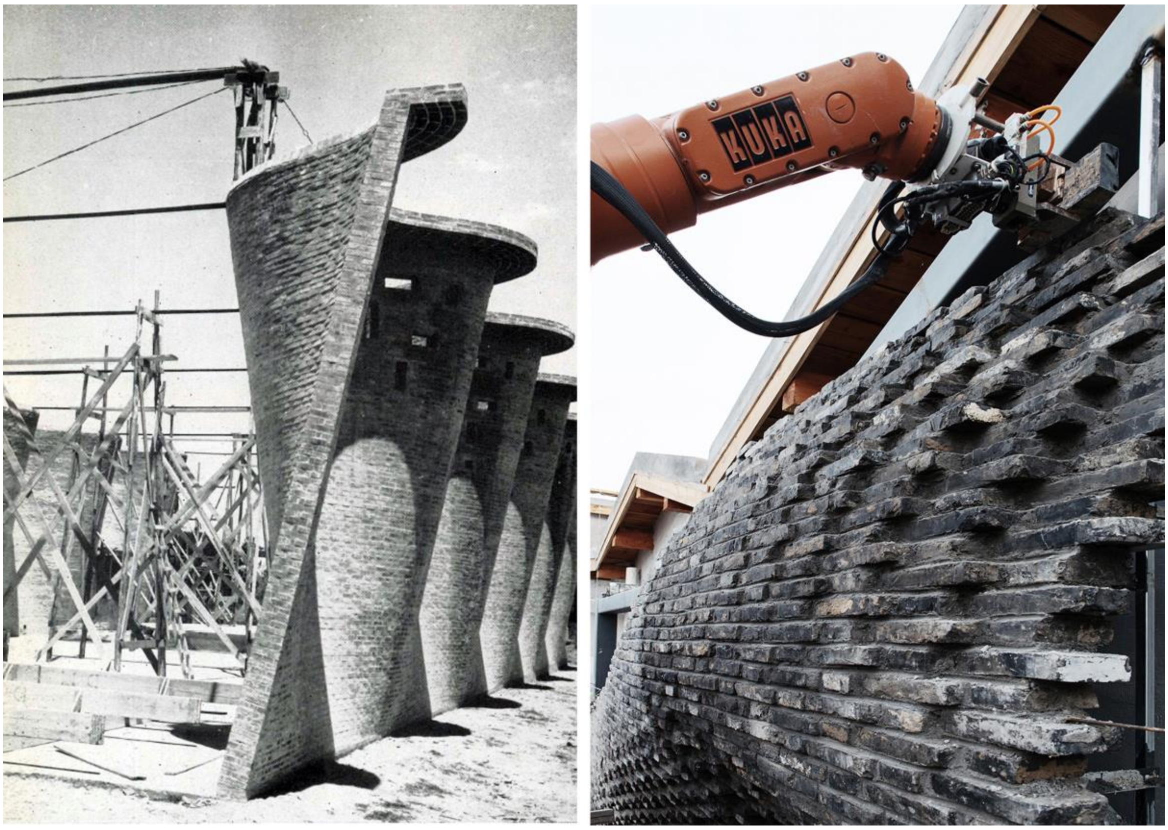
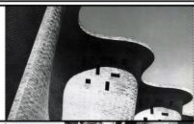


Fig 7. The nave under construction of the Church of Cristo Obrero (photo courtesy of Eladio Dieste) compared to Chi She Art Gallery (photo courtesy of Archi-Union Architects)

Fig 8. The Panot Steel Mold and Handcrafting work (photo courtesy of Escofet) compared to Ceramic tiles' molds at Villa Nurbs (photo courtesy of Cloud 9 Architects)

Table 1. Analytical Studies of the Four Case Studies

	YEAR	CASE STUDY	ARCHITECT	IMAGE	STUDIED AREA	PROCESS	TOOLS
BRICK	1952	Church of Christ Obrero, Uruguay	Eladio Dieste		Each wall covers an area of 33.5x7m	Walls, reinforced with 3mm steel wire, are crowned by a beam, of mixed brick and concrete construction	Various
	2016	Chi She Gallery, China	Archi-Union Architects		The wall covers an area of 22.5x4.5m	Undulating surface generated by being fixed on a concrete substructure	A robotic mechanical arm was used to generate the undulating surface
CERAMIC	1904	The Panot, Spain	Antoni Gaudí		Each unit has a hexagonal shape of 43 cm side	4.5 cm deep double-layer ceramic tile fabricated with a metal mold	Various
	2013	Villa Nurbs, Spain	Cloud 9 Architects		Max. dim. of a single unit 50x92.5cm	elements created using slump molding process	waterjet cut 2D alum patterns, CNC milled mold

5. CONCLUSION

In this research, the principle questions asked where regarding the effect of the digital tool utilized during fabrication process on the architectural design process, and the identification of the factors that generally hover around this relationship.

The conclusive answer to the first topic is that the effect is highly increasing and constantly becoming directly related to the formative composition of the project itself. As for the second topic, the major factors concluded were related primarily to the tool and the material (direct relationship), and that the material becomes the structure itself while the tool manipulates the form based on its strengths and constraints.

The process of fabrication/construction has constantly been detached from the design methods and materials utilized. Current research and applied case studies have shown the strong influence the fabrication techniques impose on the holistic architectural strategies followed. The study of tectonics has emphasized the spatial and visual arrangements at the expense of the materials and construction to be translated into a fully realized physical quality. Historical examples have employed similar systematic tectonic design such as in vernacular architecture. These asserted on highly tuned relations between form and structure in accordance with the materiality. In the current advancements of the process of design thinking, the fabrication tools are playing an essential role in the development of geometric strategies.

Based on deductive analysis of the selected projects, it is fair to induce that the tool is becoming a main pillar in the design process and that the relations between design and fabrication processes have become more intricate as to realize the links between the material performance, the tools and its constraints, as well as the generative design affecting the economic and environmental strategies of any particular project.

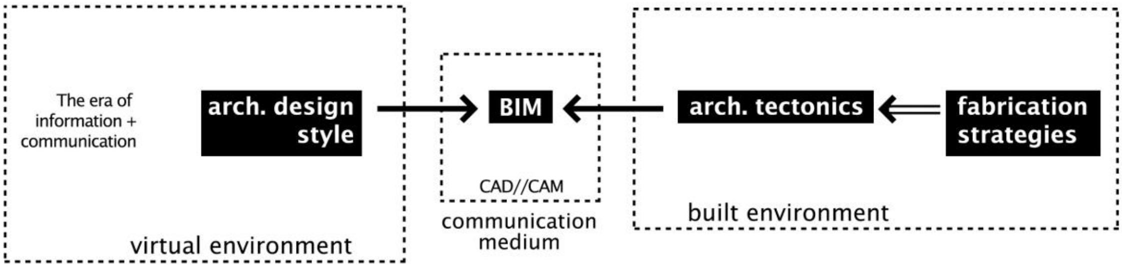


Fig 9. The relational configuration of the factors composing the architectural process

6. ACKNOWLEDGMENTS

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