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Conducting Architectural Experiments:

Some new approaches in architectural design

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***Abstract*—Paradigm shift in architectural design initiated by new technological developments has replaced conventional processes of architectural model design with dynamic transformative ones. This paper examines some of the recent developments in the architectural design through analysis of selected architectural projects and their models. The focus of the paper is the analysis of some new approaches in architectural design through implementation of digital design and novel digital fabrication technologies.**

Keywords—architectural experiments; digital design; architectural design; digital fabrication technologies.

I. Introduction

Technological digital revolution has fundamentally changed all aspects of life and work, involving all groups of stakeholders, on local, regional and global level. This digital revolution has generated the fusion of technologies within architectural design that are blurring the borders between physical and digital models. Paradigm shift initiated by these new technologies is offering alternatives to the conventional understanding of architectural design, especially in production processes with innovative fabrication practices. The paper describes and examines the implications of the latest technological developments in the architectural design process by introducing some of the most recent digital fabrication technologies.

II. Architectural experiments and digital fabrication

The architectural design research and experiments have been pushed to the new limits by the use of innovative technologies that introduce new possibilities to the process of design, fabrication and construction. These new possibilities in architectural experiments include researches in form, structure and materials, that enable arbitrary, dynamic and fluid complex freeform surfaces and have profound influence on both architectural research design and its production process. The new prospects and opportunities in approach and processes of design and production, as well as in construction systems and materials, are open to the architectural design research. These innovation researches and developments are combined, and are focusing on the investigation of digital fabrication and design robotics, and the corroborating technologies.

These new prospects and opportunities for architectural design research and construction of complex freeform surfaces were enabled by the use of Computer-Aided Design (CAD) software and Computer-Aided Manufacturing (CAM) technologies. Digital fabrication uses diverse CAD softwares, both 2D vector drawing, and 3D modeling. Digital fabrication equipment that can fabricate both 2D and 3D models, usually consists of computer-aided design and manufacturing machinery, such as Computer Numerical Control (CNC) router machine, laser cutters, 3D printers, and robotics.

Digital fabrication examines the effects of changing conditions in architectural production, such as new digital processes of design, fabrication and construction, and is making the historic shift in relationship of architecture and its production. It also opens up to new unexplored possibilities in architectural experiments. This innovative approach of digital fabrication broadens the spectrum of possibilities for construction and production by introducing computed specified building components that are fabricated directly by machine, with comprehensive data on materials and fabrication process.

Physical representation of architectural design has some novel effects that are the new unique architectural aesthetic and expression [1]. The architecture is recasting itself, and in one part is becoming an experimental investigation of topological geometries and on the other, partly a computational orchestration of robotic material production, and partly a

generative, kinematic sculpting of space [2]. New architectural design approach includes digital design media as crucial for multiplicative capability in design. Synchronized interpretation and manipulation of a computational idea, in a complex discourse, is continuously reconstituting itself into dynamic processes of form developing.

III. Some new approaches in architectural design

The generative and creative potential of the use of digital technologies and fabrication advances opening up of new dimensions in architectural design. The use of novel technologies enables development of different approaches in architectural design researches, experiments and the findings. The process of understanding the principles of computer-aided design and computer-aided manufacturing in architectural design, has particularly developed in parametric approach that uses complex parameters with advanced softwares that generate architectural form through mathematical parameters and equations, or biomimetic approach that focuses on translation of biological data of natural forms and geometries to architecture, and by using compound software factors, etc. Other approaches could be added to this classification as new processes that are being introduced are established on emerging computational based performance generation and transformation of forms. However, in this paper are analized some of these new approaches to architectural design that are based on computational/digital concepts: parametric approach, biomimetic and topological architectural approach.

A. Parametric approach

Parametric approach to architectural design is based on parametric design principles where architectural form is generated and described throughout mathematical parameters and equations.

Equations are used for defying geometries that are mutually linked and relationships between objects that make the architectural form, [3]. Interdependencies between forms are defined by inserted values in mathematical and geometrical equations that establish transformation and relationships between the forms of architectural design. Insertion of different values to the parameters generates different object transformations and configurations, together with reconfiguration of geometrical relationships of linked objects. This new parametric architectural design approach enables new architectural research in form generating process, (Fig 1).

Several software programs (e.g. Grasshopper 3D, Karamba, BullAnt, Hummingbird, etc.) use integrated graphical parametric algorithm editing tools to generate form. Previous knowledge of programming is not necessary as it easily enables designers to generate complex parametric forms that can be changed interactively in 3D modeling linked tools. Complex dynamic, curvy transformed objects can accomplish a resilient interaction and integration of design process with fabrication of architectural elements, at different scales, from small design

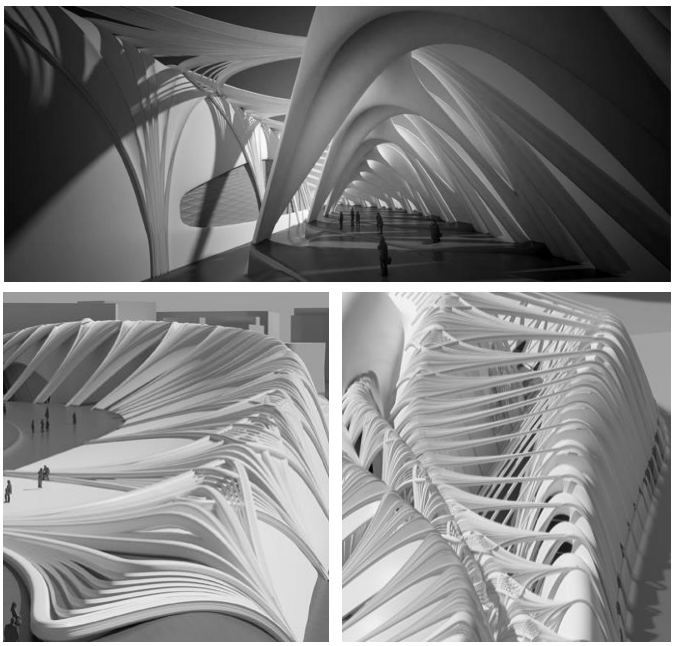

Fig. 1 Parametric approach. Parametric brickwall study form –AA student project 0RN8, Tutors: Patrik Schumacher / Christos Passas, Architectural Association School of Architecture, London, UK, 2010

scale to the large, urban planning scale. Parametric approach can be illustrated by the ORN8 model research project, implemented at Architectural Association School of Architecture in London, (Fig 1). The aim of this research project was to critically reinterpret the rules and logic of Gothic structures and constructions, by applying present-day parametric tools and techniques.

After using basic parametric experimentations, based on the reinterpretation of the rib as a proto design element, further parametrization focused on the Gothic vault bay, and mesh geometries as well, [4]. The application of colour was used as the key instigator of a parametrically evolving parabolic vault bay system.

B. Biomimetic approach

Biomimetic approach is based on the concept of biomimetic architecture or generative, evolutionary architecture that uses biomimicry as imitating or taking inspiration from natural forms and processes for solving problems and offers innovative solutions for future developments in architecture, [5]. Latest technological innovations show how biomimicry, applied to architecture, can generate more sustainable built environments.

Biomimetic architectural design approach expresses architectural concepts as generative, or evolutionary, with computer models used to enhance and verify this progress, [6]. The biomimetic architectural experiments can imitate forms, functions, and processes from nature and can do that either by taking design to nature or by bringing natural forms to design.

Biomimetic approach is using biologically inspired elements to solve design problems, as it takes inspiration from nature to produce novel architectural design. Some of the most advanced aspects of this approach have the potential to contribute to the built environment in terms of sustainability and resilience. Other aspects within this approach, that bring nature to design, identify design problems and then try to find a nature's solution to a similar problem, in terms of function or process. In that second approach, architectural design mimics natural processes and has a potential to research towards regenerative architectural design, (Fig 2).

This architectural approach is seldom used as a tool to increase the sustainability of architectural design, structure and materials. The actual potential for increasing sustainability of biomimetic architectural final design can be found in the process of incorporating mimicked nature's principles at the earliest possible stage in design. Although sustainability principles are achievable, the materials, structures and even technologies following biomimetic architectural design are not fundamentally more sustainable than conventional ones, and, therefore, there is a great potential for research developments in these fields.

The biomimetic approach of the ICD/ITKE research pavilion project, at the University of Stuttgart, demonstrates novel computational design and robotic fabrication strategies as case studies for new design concepts, fabrication processes, and material systems, (Fig 2). The aim of this new architectural approach is to extend the range of architectural design scenarios and multiply its capacity to perform. It opens up new aspects of research and possibly some fully developed building systems, design and fabrication processes in the future. This prototype research pavilion investigate design strategy for the biomimetic architectural research of natural fiber composite shells and the development of novel robotic fabrication methods for fiber reinforced polymer structures [7].

Fig. 2 Biomimetic approach. 2a) ICD/ITKE research pavilion prototypes, 2b) Detail of ICD/ITKE research pavilion, Tutors: Prof. Menges, prof. Knippers, University of Stuttgart, Germany, 2013-2014

However, a transfer of natural construction principles to architectural applications is not possible through this method, as it involves exclusive elements that require broad formwork and complex molds [7]. Altogether, this prototype research pavilion shows that the multidisciplinary biomimetic research approach can lead to performative and material efficient lightweight constructions and explores novel spatial qualities. This research shows how the computational synthesis of biological structural principles and the complex reciprocities between material, form and robotic fabrication can lead to the generation of innovative fiber composite construction methods [7].

C. Topological approach

Topological approach is exclusively determined through its relation with all other elements within the system, based on the identity and the position of each element or part. The formal order of elements is established by their locally defined mutual relations. Topological approach includes many possibilities of generated space that usually has curvilinear forms of variations. New, unpredicted forms may emerge, with random variations, generated by the built topology of self-varying deformation [8].

The highly curvilinear surfaces of continuous topological nature, rarely used for architectural and urban form generation, open up new spatial and tectonic thematic ramifications of such non-Euclidean forms, knowing that such forms commonly do not have a proclaimed center. Therefore, this decentralized order generating process is distributed within and at the same time reliant on a population of elements. In that sense, construction of these topological geometries can be computationally possible by the use of Computer Numerical Control (CNC) fabrication processes, e.g. milling, cutting, subtraction, addition, and other forms of fabrication.

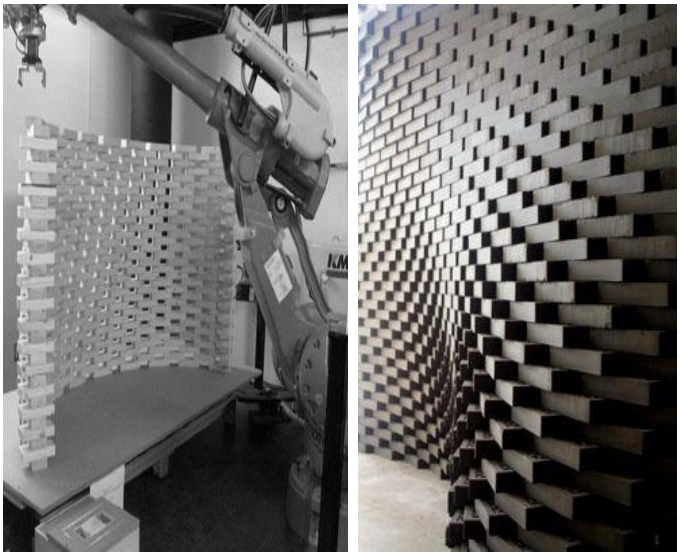

Fig. 3 Topoplogical approach. 1a) Wall built by robots; 1b) Detail of the wall; On the Bri(n)ck, prof. Rocker, Graduate School of Design Harvard University, Cambridge, USA, 2010

These complex curvilinear topological geometries are produced similar to conventional Euclidean geometries that contain planar shapes forms, thus potentially making conventional modular mass-production obsolete.

A digitally generated and fabricated wall, consisting of wooden bricks, presented within an exhibition at the Graduate School of Design, Harvard University, was the outcome of a synthesis of computer generated design and computer-aided construction research, putting forward the potential of digital fabrication techniques and the role they have in the education of architects [9]. With a modular unit of the masonry brick, the project team developed a systematic aggregation making a wall consisting out of 4100 bricks. The set of algorithms, that takes into account material and technical parameters applied, create a curved wall structure of a simple rectangular brick module with brick space and pattern. Final design scheme is realized by robotic machine, through an automated process based on script of algorithms.

IV. Conclusions

New digital technologies and developments induce fundamental and inevitable paradigm shifts in contemporary architectural design, displacing many of the well-established conventions towards digital ones. These new paradigms and concepts open up dynamic development to architectural research approaches. The computationally generated complexities have changed relational anticipation between architectural design and its representation. Digital technologies have initiated developments of dynamic, complex and non-linear form generation, through the use of new concepts, softwares and machines that enable creation or fabrication of such forms.

New digital technologies are changing architectural design and construction processes. Digital technologies integrate architectural research, design, process of construction and assembling of buildings, and open up new approaches to architectural design….

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