Contextual customization of design process

DESIGN THROUGH THE DIGITAL AND THE MATERIAL

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ABSTRACT:
In contemporary world, digital technologies have initiated new architectural languages and have eased the way to communicate them directly from initial design phase to production facilities, allowing for the construction of complex geometries with the use of ever evolving techniques and tools. When the emergence of a substance depends on the material behavior, the design interest shifts towards the 'formation' instead of the 'final form'. Regarding these the design procedures will be discussed from the premise where architecture will be perceived through an evolution process that deals with the coherent variables of elements and shifting parameters within a context. However, there are crucial questions about its application in the contexts which have lower access to contemporary technologies although digital technology has already influenced almost every aspects of the culture of the respective context. Besides, the huge production cost has limited its adaptability in many under developed and developing countries where the construction field relies mainly on traditional and low-tech methods. The paper is an effort to give attention on exploration of the new-found freedoms of material computation in close connection with the respective context by inventing new design processes, material applications and custom devices. It is the time to experiment with flexible, mobile and low-cost fabrication methods applicable to different scenarios while achieving the complexity of the contemporary architectural geometries. Thus an equal focus has to be given to speculate about projects that are site-specific, customized and adapted to local climatic conditions and technical know-how, in areas that traditionally have limited access to new technologies.

KEYWORDS:
complex geometries, material behavior, custom devices, low-cost fabrication, design process
1. Introduction

Technology and culture have formed a feedback loop throughout the world history; advances in technology have accelerated the pace of innovations in different socio-cultural aspects; in turn, these cultural developments have fed back to the discoveries of new technologies. The contribution of contemporary techniques lies in the progress of a culture that is driven by a machinic process which produces emergent results as an outcome of a rigorous understanding of complex natural systems. Thus the construction solution for the complex geometry of contemporary architecture necessitates the development of new methods and tools, and this in turn demands the seamless integration of digital modeling and computer-aided manufacturing.

However this loop between the architectural advancement and contemporary technology are often burdened by the constraints of the place, time and available resources. Since the shift in concept of designing the ‘formation’ rather than the final form are being taken forward by intense application of the ‘digital’ from the very beginning of design process to the end of manufacturing process, there arise crucial questions about its application in contexts which traditionally have lower access to high-tech methods and machines.

There is a growing interest in research field, if not very evident in the current practice trend, to intervene the possibilities of customization of this ‘shift’ in architectural language that questions the standardized industrial mode of production by addressing the whole procedure as an integral part of the local knowledge of craft and construction responding to the specific cultural context. The paper emphasizes on the change that is required in our approach toward materiality and the design process.

2. Research Methodology

The paper attempts to explore the new-found freedom of material computation, inventing a design process stemming from material behavior based on specific building scenario and available technology. It will focus on the hands on experiments and the operation of custom fabrication device to control the material formation process as an integral part of the design process. With a brief study of the pattern formations in natural systems and the work of the precedents who have set up references to work with material behavior applying laws of physics, the research explores a design process with flexible, mobile and low-cost fabrication system to generate complex digital outcomes.

Natural material formations will be briefly discussed to understand how sameness can give rise to diversity and how these rules of varying patterns can be implied to inanimate materials to make the process responsive to minute changes in each and every cross sections and thus achieving efficient structures. Structures designed/built by using material physics as the core form finding agent have been studied as references to achieve newer complexities. Recent case studies of academic and research projects of complex geometries exhibiting the formation process in the form of the final product, done by the authors, have been briefly discussed.

The rise of the ‘digital simulation’ which later gave the thematic and procedural base for the contemporary architectural practices like ‘digital materiality’, is to be linked, where the conceptualization of the design and the construction procedures informs about the infinite perceptual and construction possibilities of architectural built form. The role of an architect is also to be addressed regarding this kind of procedural practices.
3. **Formation process in Nature and Design through Material Behavior**

Natural structures possess the highest level of seamless integration and precision with which they serve their functions (Janine M Benyus: 1997). Nature's ability to distribute material properties by way of locally optimizing regions of varied external requirements, such as bone's ability to remodel under altering mechanical loads, or wood's capacity to modify its shape by way of containing moisture, is facilitated, fundamentally, by its ability to simultaneously model, simulate and fabricate material structuring (Oxman Neri: 2010).

Optimization process of Nature by organizing material density by differentiation and integration in the local level affects the global geometry of the whole system forming complex emergent patterns. This complexity is heterogeneous, with many varied parts that have multiple connections between them, and the different parts behave differently although they are not independent. Complexity increases when the variety and dependency of parts increases. The process of increasing variety is called differentiation, and the process of increasing the number or the strength of connections is called integration. Evolution produces differentiation and integration in many 'scales' that interact with each other, from the formation and structure of an individual organism to species and ecosystems. (Weinstock, Michael: 2004).

![Figure 1: Natural Growth Pattern; a: membrane of eggshell: fibers are articulated in such a way that they distribute load equally on the surface area. b: Human femur made of mathematically precise, crisscrossed pattern of fibers that reduce bones weight while giving it maximum strength against multiple forces. Figure 2: Construction process in Nature; a: Strong and compactly woven nest of the weaverbirds: constructed by systemic interlacing of filamentous elements. b: Termite mound constructed by a distributed material system responding to various functional requirements.](image)

The behavior of a form evolved from self-forming process, has to be tested with physical experiments to intervene into the realm of geometries emerging from material behavior in full architectural scale. Self-forming processes can be systematized by two distinct approaches. The first system emphasizes the force, which acts in a structure or can be transmitted by it, or which was acting during its development. The second system emphasizes the form of the developing object because its form is a primary parameter in the evaluation of a structure. Form and force are correlated, in that the form of a structure can be determined as the state in which the forces acting in and on it are in equilibrium. Furthermore, the flow of force can be shown through physical modeling. (Emergence and Design Group in Conversation with Frei Otto, 2004). The ability of some materials to self-organize into a stable arrangement under stress has been the founding principle of structural form-finding in the physical experiments of Gaudi, Eissler and Otto. 'Organization' here refers to the reordering of the material, or the components of the material system, in order to produce structural stability. (Weinstock, Michael, 2006).
4. Existing Technology and Multiple Potentialities

The complex interaction between form, material and structure of natural material systems has informed new industrial processes, generating new possibilities for controlling the whole process bit by bit with difference and repetition. Digital technologies have initiated new architectural languages easing the way to communicate them directly to production facilities for the construction of complex geometries with the use of high-tech CNC machines, Robots, 3D printing, Contour Crafting etc.

This technological shift has inevitably influenced the contemporary architectural expression easing the construction of fluid smoothness of free forms with intricate control of details. It has explored the digitally crafted non-uniform patterns and structures. According to Gramazio and Kohler this ‘Digital Materiality’ is characterized by: a. unusually large number of precisely arranged elements, b. a sophisticated level of detail and c. the simultaneous presence of different scales of formation. Despite its intrinsic complexity there should be an ‘intuitive’ understanding of the system to address our ability to recognize naturally grown organizational forms and to interpret their internal order.
Digital materiality is not rooted solely in the 'material world' and its physical laws such as gravity, or in material properties. It is also enriched by the rules of the 'immaterial world', which is to be perceived and experienced by the 'digital logics'. Gramazio and Kohler note the sense of becoming and commented, “In case of an observer, the tension spans the intuitively understandable behavior of a material and the design logic, which may not be immediately obvious. The logic can be sensed, but not necessarily explained. This obscurity seduces our senses, sending them on a voyage of discovery and inviting us to linger and reflect.” (Gramazio, Fabio and Kohler, Matthias, 2008)

5. Customized Design Process:

Digital materiality is generated through the integration of construction and programming in the process. The digital tools like computer works as design tool but cannot substitute a designer in the procedures of design. Here the designer has to design the sequence of individual steps of the whole process where the sequences of the construction steps are to be synchronized with construction, the knowledge and art of putting individual building components together. It is no longer about designing the form that will ultimately be produced, but the production process itself. The design incorporates the idea and knowledge of its production already at its moment of conception. As named by Gramazio and Kohler, 'Digital Craftsmanship', thus continues the tradition of construction in architecture. (Gramazio, Fabio and Kohler, Matthias, 2008)

It should be mentioned that practical 'hands on' experience has to be incorporated with the digital for finding process. The practical experiments with the material formation process derives the rules for the digital computation. It is necessary to develop programming languages that account for the fact that when designing, the exception is often just as important as the rule that means hierarchical dependencies can change throughout the design process. The designers can intervene in this evolutionary process by developing their own dialects that take up the subjects of construction, materials and space. The architects should choose their means of construction consciously and master their tools. Accessing these generic tools enables architects to create their individual design instruments and thus generates diverse forms of expression. Digital materiality has the tradition of construction connected to it and it changes the culture of architecture, both in its expression and in its productive capacity.

![Figure 5: Digitally Controlled and Digitally Informed Design Process incorporating material computation within specific context.](image-url)
6. THE SHIFT AND THE CONSTRAINTS

'Digital Materiality' leads us from the design of static forms to the design of material processes. It is a conceptual way of designing with architectural parameters, conditions, relationships and degrees of freedom. In this way of conceiving architecture, processes are concrete sequences of operations, procedures that have to be designed. These procedures might have a determined beginning and an end but the possibilities are 'open-ended'. There can be multiple procedures running at the same time with the continuous 'feed-back' from the contextual setting.

When, architecture becomes the design of material processes, there will be no longer a static plan before the designer, but a dynamic set of rules. A set of rules are the open parameters for the design process and a very fundamental rule can be implemented even late in the process. This type of design, detached from a drive towards form while doing justice to the material substance of architecture, including its sensual qualities. Designing architecture as processes thus strengthens the central role of the architect.

The technological advancement might enable architects to explore complex geometries but, it is also questioned for the large amount of financial involvement. Again, in case of its' implication in a specified construction scenario which lacks high tech manufacturing equipments, this could lead to the risk of the monopolization of novelty in the built environment. Digital construction is highly depended on the digitally driven tools and those are being in a state of development. Using these tools requires a very high-end technical know-how which is unavailable in most of the contexts. This situation might rouse the sense of 'royal' attitude towards the movement that addresses material behavior in the design process.

7. TOWARDS LOCALIZATION

The context taken primarily is Bangladesh where warm-humid climatic condition prevails and questions the reusability and energy efficiency of the construction formworks like; steel, wood, bamboo which are apparently widely used. Again, inclusion of the digital construction processes in its original form, will have a very bleak future regarding the scarcity of digital tools and technical knowhow.

In order to achieve simplicity and truth in the process of constructing new construction method has to be pursued where materials assemble to controlled complex geometries, according to a design system that is the result of a thorough investigation of how these construction materials behave. The emphasis is to be given on the available material specification that would accommodate innovations in construction procedure and innovative formwork using local construction techniques. In case of Bangladesh digitally derived formations can be transformed through rethinking the possibility of portable tools and flexible formwork using low cost local materials and technical knowledge. Sustainability of the whole procedure should be justified with local context and climatic conditions.

Following are the Academic examples done in the Masters Studio 'Digital Tectonics' and post graduate Research Program 'Open Thesis Fabrication'ed by Marta male Alemany respectively at the Institute For Advanced Architecture of Catalonia (IAAC) where the research projects explored the innovative material processes, custom devices and computational methods that could be applied to different contexts that depend mainly on low tech construction procedures. These studio projects are done in a very advanced scenario in terms of construction technology that sets the background for the quest for achieving the computer driven formations by using apparently low tech local construction procedures for the context of Bangladesh.

Research Example_1: The Masters Studio project investigated the work flow between computational design and formation methods, stemming from material behavior, exploring programmable custom devices. The thesis project done by a team of four students targeted recently demolished sites and reinstanting the site found broken bricks as potent design components. The project utilized the atypical
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The project succeeds in establishing a site based active design system with a real-time interaction between the design and execution. The 3D scanned broken bricks are reproduced into a digital platform, sorted and the design outcome is evaluated conforming predefined performance criteria. The design outcome is transferred onto a portable device, such as, Tablets / I-Phones, for execution. Due to the complex shapes of the brick units, a certain level of precision needs to be maintained for the stability of the structure. To monitor the execution two webcams are installed at the execution site. It firstly analyses the existing site conditions and sends the data to the designer to evaluate the design. Secondly it monitors the execution process with help of fiducial markers confirming the position of each brick.

Fiducials sync the position of the brick on the digital and physical mediums and updates the position of the bricks as the bricks are laid. This helps in cross checking the exact position of the bricks. The data of the fiducials is sent to Processing. Processing acts as a bridge to link with Grasshopper. The data is received on grasshopper where the digital bricks models respond to the real time changes during execution. If there is any change during the construction this real time evaluation process immediately signals the workers to rectify the error. This opens up an opportunity to set up the design process in real-time by continuing the active interaction between the execution team and designer throughout the whole process.

The Process is demonstrated by making one-one prototype with site found materials at a historical mountain villa to propose new structures. The project is conceived as a portable design system which

Figure 6: Components and technologies used in the process.

Figure 7: Sequential steps of the design process with broken bricks of unique sizes.
can be executed at sites which traditionally have lower access to technology. It can easily calculate required energy, manpower and resources thus forming a sustainable design system while achieving the complexity and intricacy of computational design.

![Figure 8: Research Example_1: Evolutionary logic applied using rhino grasshopper to find the 'best fit' from each generation for achieving different fitness criteria set by the designer with broken bricks of unique shapes. Fitness criteria were to find different architectural elements such as contour surfaces, enclosures with minimum number of bricks, curved walls, screen walls etc.](image)

Research Example_2: The aim of this 4 months research done by the author under the Open Thesis Fabrication program was to design a mechanism to generate a structural screen stemming from material behavior responding to certain stimuli as observed in natural growth processes. The generative process focused on the optimization of material organization according to the parameters such as applied stress, environmental conditions etc. A mono-material structural skin was proposed by generating pattern under different support and loading conditions to achieve lightweight structures of complex shapes. A system of simple Fabric Form-work is proposed to generate doubly curved showing variable cross section that could be achieved only with hi-tech technologies (3D printing) and not by conventional construction method. The challenge was to keep the manufacturing process as low-tech as possible to make it applicable in different contexts.

![Figure 9: Rules are developed from the hands on experiments with Fabric and concrete, to generate 2d pattern to be sewn on fabric panels.](image)

Fabric's unique characteristics of forming double curvature have been explored to make the process truly unique for the combined material system of fabric and concrete. Hexagonal pattern, with varying radius derived from the physical experiments, was sewn on a flat fabric panel. The control points between the hexagons were used to achieve the complex formations out of the simple formwork. From the physical experiments with fabric material it has been observed that there is a certain relationship
between the width of the channel between the hexagon pattern and the height of the mid points of the base hexagonal grid while the points are pulled up to the maximum extent. So the upper surface of the prototype will follow the curvature of the target double curved surface with the height variation of ‘spikes’ which will generate a surface with varying thickness and porosities.

Research Example 3: The potential of customized devices or tools within the localized construction procedure, through the thorough study of physical models informed by digitally based pattern formations and its application in the context of Bangladesh addressing existing constraints is the current research agenda.

This is an ongoing design research where the target so far achieved is to introduce the logic of ‘digital materiality’ by using simple low-tech construction process with affordable and portable tools and formwork. The set agenda was to simplify the perception of construction procedures and combine them in a way where the results might develop into some obvious functional and aesthetical formations.

Current state of our research agenda is a small installation which is a meditation and preaching space for semi-religious and social institution in Bangladesh which is taking its shape as a start to demonstrate the construction of a ‘formation’ computationally derived from very simple set of rules given to brick modules.
The local mason was given 3 to 4 set of rules to follow and assemblage of brick formation to start the construction. The set rules has fed-back the assemblage and the mason constructed the obvious openings, unique edges and corners and surfaces with undulation of the built-form. Though the end result here might not be something unique in the sense of digitally transformed formation but, the learning process gives us the base for dealing with multi-parametric cases through local ‘hands-on’ construction process for the initial instances.

8. Open Ended Discoursive Remarks:

The probability of encountering discoveries and innovations is accelerated by using computational means of design. Architectural forms are produced in the course of the design and materialization process and takes on its character bit by bit. Digital materiality changes the ‘physis’ of architecture and ultimately the image that society has of architecture.

On the basis of this current state of the ‘complex formation’ generating exercise derived from the material behavior, using Rhino Grasshopper, 3ds max and AutoCAD as the main computational tool, the next steps will focus on more ‘technical issues’ relating structural and environmental factors using
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computer simulation. Thus the research is an attempt to unite the delicacy of material computation and the artistic imperfection of the handcrafted into an efficient structure facilitating local techniques and masons with affordable custom devices.

The Bangladesh based practice studio is now working on the application of the research project with ‘flexible form-work’ done in a very advanced setting in Barcelona. A Multipurpose hall is being proposed with fabric formed curved surface. Parametric perforations will be introduced on the surface to respond to the environmental and functional aspects. The material will also be optimized by varying the thickness of the surface.

Figure 14: 3-D visualization of the proposed Multipurpose Hall with fabric formed perforated concrete surfaces with the traditional Temple Complex on the background.

Here a question can arise, why does a design need an interfering designer as it is an inherent part of the process (as matters are acting in own self-organization system); this can be argued by saying that, designers now can control that process by de-coding and delivering feed-back information while achieving the desirable pattern and formation. Hence it should be understood that while revealing the ‘material behavior’ and executing the formations architects are enriching the contextual affinities of a built-form. Here it is important for the architect to customize the ‘software’ that is going to be used and it solely depends on the architect’s sensibility and understanding of the complexities of the universe and this guides the uniqueness in the architectural design procedure where a sensible architect becomes the ‘author’.

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