{IN}FORMED PANELS

Towards Rethinking the Precast Concrete Industry in the UAE

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Abstract. The convergence of digital design and fabrication technologies have offered architects and designers the means by which to develop customized architectural artifacts, ones that goes beyond the standards of "one size fits all". Such applications have been applied extensively in various architectural practices, and specifically in the realm of industrialized building production, given that they present a suitable model. Although unrecognized within standard precast concrete production, current research acknowledges the need for advanced computer applications for shifting the industry into a digitized process. This paper represent a critical phase of an ongoing research endeavor that aims at rethinking the precast concrete production in the UAE, and MENA region for housing typologies. The project explores possibilities of a new protocol that is focused from design to production, relying on performative design strategies, and possible optimized for large format 3D printing of concrete elements. The aim is to develop an integrated façade panels system that is tailored for design and production; an approach that goes beyond current industry practices.

Keywords. Precast Concrete; Industrialized Construction; Evolutionary Design; Optimization.

1. Introduction

Concrete is one of the most usable materials in construction worldwide, and specifically in the MENA (Middle East and North Africa) region. It is considered as a cheap composite due to low cost of raw material. Additionally, it is a strong material in compression, durable, resistant, and versatile. One of the most common applications in concrete construction is precast concrete, a production model that operates by building up offsite molds and formwork for each specific project. It is used for walls, floors, and structural elements. Once completed, these components are delivered to construction site, then assembled by cranes to form a building.

There are several reasons why architectural precast has gained popularity in the past few decades and particularly in the MENA region. First, architectural precast

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offers long term durability and require minor maintenance, given that it achieves high strength relying on high cement contents and low water-cement ratios, coupled with good compaction and curing in a controlled factory environment. Second, the process of developing architectural precast allows for diverse surface and volumetric articulations, all in a cost effective manner. The material is characterized with high plasticity, and can be designed for variable appearances. Third, being produced within a controlled factory environment, this leverage quality and accordingly has economic benefits with regard to initial and life cycle cost. Last, with growing interest in environmentally conscious material, it is argued that architectural precast can be designed to provide high degree of energy efficiency in buildings. Such a trend includes integrated shading devices within façade panels, and specific wall thermal characteristics through combined insulation in the form of sandwich panels (PCI 2017).

Withing the United Arab Emirates (UAE) construction market, precast concrete production has been growing remarkably in the past decade. Market research indicates that the 6 billion AED industry in 2015, comprised almost 30% of the total construction. Multiple reports refer to precast concrete as a 10% cheaper solution than conventional construction, because of lower cost in labor, time-saving, while offering significant environmental benefits. Additionally, it is argued that such a system is driving creativity in the real estate sector as architects have greater leverage to develop intricate designs that can be produced off-site (Kumar 2011).

Recent advancements in material processing though the use of cutting-edge digital design and fabrication technologies have offered architects and designers new modes of creativity, and the means by which to develop customized architectural artifacts, ones that goes beyond the standards of "one size fits all". Such applications have been applied extensively in various architectural practices, and specifically in the realm of industrialized building production, given that it presents a suitable model. Although unrecognized within standard precast concrete production, current research acknowledges the need for advanced computer applications for shifting the industry into a digitized process. This research thus proposes a novel framework and a systematic group of methodologies for the design and optimization of a façade panels system in response to specific contextual conditions.

The framework is based on developing an algorithmic process to manipulate and optimize the parameters of a self-shading system, thus result in a unique, and orientation-responsive design. Such an approach derives its logic from a computational design processes, where a evolutionary solver employs a form-finding strategy, supported by simulation tools, to optimize window shape and extrusion based on orientation.

In order to achieve the research objectives, the paper is structured as follows. The first section is denoted with briefly shedding the light on precast concrete practice in the UAE with focus on design and production practices. Then, the design and optimization framework is explained, resulting in the taxonomy of developed façade panels. Finally, we evaluate the process and describe potential of future research.

2. The precast concrete industry in the UAE

As mentioned earlier, precast concrete production has been in the GCC market since the 1970s, initially in Saudi Arabia and Kuwait, but then in the UAE. Currently, the UAE market has been growing immensely, supported by implementing advanced infrastructure in precast, where factories pursue the latest technologies in production line. According to statistical data provided by the Abu Dhabi Chamber of Commerce and Industry, the precast sector in the UAE is valued at $1.6bn, employing over 25,000 laborers and technicians working in in around 20 manufacturing facilities, with the construction cost of each of these factories ranging from $50m to $350m. The industry is considered a key revenue-generating sector, where pioneer companies are driving a new trend in the construction industry through offering high-quality products and maintaining safety and environmental standards (Kumar 2011).

The UAE housing sector relies extensively on precast concrete where it plays an important role in supplying the housing market with diverse products such as single family homes, and specifically projects funded by the government. The common practice is based on the production of wall panels in an engineering to order fashion. For the sake of standardization and cost saving, these panels are often replicated within the same housing development without considering various factors like context, orientation, climate, and user requirements. One of the recently projects Al-Falah community, a vast national housing development in Abu Dhabi that utilized precast concrete components. The project; consists of 2069 housing units, including only nine variations of single family homes in style and size. Figure 1 represents images of the project.

Figure 1. Images from Al-Falah housing project showing an aerial view of the site, and one of the single family houses by the company Gulf Precast (Source: Gulf Precast 2017).

A major outcome of our study on market practices is the deficiency of technological applications, where it is commonly limited to 2D drafting and 3D modeling, for the sake of clash detection, and issuing fabrication orders. Additionally, production is being dominated by manual labor, though automation takes part at some stages of the process. while we believe that the industry’s diverse business practices evidence several on-going concerns: targeting affordability, responding to environmental challenges, and contributing to innovation in the homebuilding sector, we argue that a major drawback is that lacks the opportunity to develop more advanced production protocols. In that sense, it is understandable that there is a clear gap between what has been proposed in research, and current precast concrete trends in the UAE. In order to respond to such an argument, we envision a road map that the industry can pursue to highly benefit from recent advancement in digital tools in design and fabrication.

3. Redefining façade panels : Optimization methodology

The interest in generative design processes has been growing recently as a result of advances in applications of computational methods, supported by models from the field of Artificial Intelligence (AI). Such an arrangement has offered designers the means by which the design process can be informed by a series of parameters. One of the powerful tools has been identified as evolutionary computing, expressed as an application advanced algorithms employed by designers to automatically improve the performance of design processes. Such algorithms set the stage for numerous creative solutions, as they possess the ability to generate and suggest new design alternatives for a specific problem. Evolutionary algorithms are in some cases classified as heuristic algorithms, due to their search-oriented nature. They define a design problem in terms of a search, in which the search space contains all possible solutions and a point in that space defines a solution. Evolutionary search algorithms express their full potential by simulating the process of natural selection and reproduction on a computer, thus shaping the evolution of solutions in response to a problem. These algorithms therefore consider a large group of solutions at once, rather than working with only one solution at a time (Bentley 1999), following a learning process.

Evolutionary computing is commonly applied towards optimization of a specific design solution. In another word, it enables exploring a pool of design alternatives then pick the fittest solution of a well-defined problem, driven by single or multi- objective optimization (Eiben and Smith 2003). The process can be set for single or multi-objective, based on the type of the design problem. Pertaining to architecture, the notion of optimization has been explored towards various types of design problems, including space layout planning (Gero 1996), (Jagielski, I., & Gero, J. S.,1997), form finding (O'Reilly and Ramachandran,1998), and opening size and location (Tuhus-Dubrow and Krarti 2010). Commonly, when the case relates to building performance, the optimization model is combined with a simulation engine to insure adequate solutions.

One of the relevant examples to our proposed research is the paper entitled "A design optimization tool based on a genetic algorithm" (2002). The paper proposed a generative tool that can assist designers to generating and evaluating particular features of a solution towards an optimized behavior of the final building configuration. The tool applied Genetic Algorithms (GA) as a generation and search media to look for optimized solutions with regard to lighting and thermal performance of the building. The GA is first used to generate possible design geometrical answers, which are then evaluated with regard to lighting and thermal behavior using a detailed thermal analysis program. The results from the simulation are consequently used to further direct the GA search towards finding low energy solutions, by assigning strength scores, to the studied problem. Solutions can be visualized via AutoLisp routine. The system targets optimization rather than simulation, and results proved to be highly satisfactory.

Pertaining to precedents exploring potential of computational design processes and its possible application with precast concrete system, the paper “Parametric precast concrete panel system” Bell (2015) proposes a series of parametrically driven geometries toward producing formwork based on quantitative and qualitative data. The research proposes three types of panels based on function: solar, aperture, and sound diffusion. Solar panels use forces from project orientation to coordinate panel geometry with specific surrounding context. Panels can either integrate solar photovoltaic or create façade fenestration. The complex geometry of the panels would require a Computer Numerically Control (CNC) milled mold. In order to overcome some of the draw backs of the proposed methodology, Bell (2017) proposed further developments to this research. However, the proposal lacks a simulation model to validate the effectiveness of the geometry’s response to the surrounding

In response to precedent efforts, combined with the goals of the intended research project, we propose a process that aims at optimizing self-shading façade system, at the level of a single room to start with and after generating a building prototype that aggregates all of the optimized panels in one BIM model. We relied on existing computing tools that combine design, optimization, and simulation. We employed a series of plugins and-add on components within the visual programming platform Grasshopper to develop the catalogue of façade system optimized panels.The following section elaborates on the process with specific focus on design procedures, and parameters.

3.1. PANEL TAXONOMY: THE MECHANICS OF THE PROCESS

One of the features of the precast concrete industry in the UAE is the practice of a production to order model, one that in many cases lacks a modular strategy. In other words, façade and interior wall panels are designed and produced on-demand in response to project requirements. While such a trend allows for design flexibility, and offers high levels of customization, yet we believe that it does not comply with the economies of industrialized production. In that sense, we initiated the design process following a modular strategy, where precast panels are designed based on of 1.50 m wide module. Based on exploring the market standards with regard to opening sizes, these panels are denoted with hosting fenestrations. To leverage typology- based flexibility, we devised two variations: narrow panel of 1.5m and a wide panel 3.0 m wide. We anticipate a flexible, adaptable, and customizable modular system. Nevertheless, the design system is set to accept further iterations in the design of wall panels. Figure 2 represents the classification of wall panels.

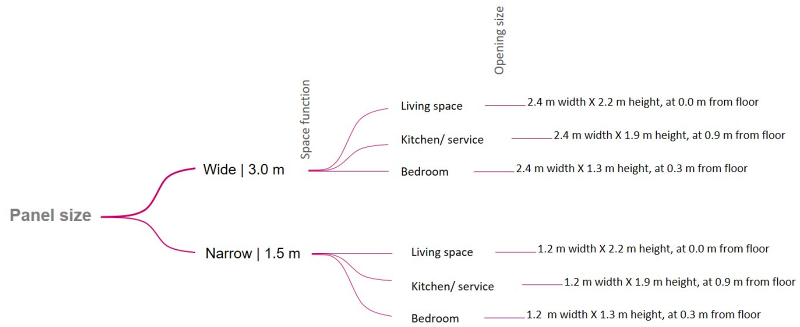

Figure 2. Classification of façade panels based on size and function.

Given the climatic conditions in the UAE, the need for a shading system can be considered inevitable. In fact, the design of climatic features dates back to the 1950s, when construction of houses employed masonry structure, resulting in simple, practical and functional expressions to meet the demands of a harsh environment. While expressions at that time took the form of a pattern- based sun screens, our approach for the design of a shading systems stems from the plasticity of concrete as a material, and advocated by a computational strategy. We initiated the process with a series of assumptions derived from examining residential design trends in the UAE, with specific focus on opening size in relation to allocated function.

Pertaining to the shading system, the pursue of an integrated façade scheme dictated the utilization of a self-shading element, one that emerges from the panel itself. Accordingly, the element has been set within a predefined volume, and controlled by a series of parameters in the form of vertices in x,y,z directions. The purpose is to allow for flexibility in performance optimization, through manipulating various parameters. additionally, in order to control the generation process, a set of constraints where involved, related to housing design and openings guidelines in the UAE.

A multiplicity of tools and plugins were utilized to develop the optimized panels and customizable scheme. The process is initiated with devising a basic room model in Rhinoceros (Rhino3D) with one glazed opening, hosting a non-uniformly extruded virtual shading element. While the shading element is set to operate as dynamic component, at this stage it the follows perimeter of the fenestration. As mentioned earlier, the opening size and virtual shading extrusion bounding values, and the constrains on the direction of movement between vertical and horizontal elements are all predefined settings, responding to functional requirements and following housing guidelines in the UAE. This generic configuration is then fed into Grasshopper, the visual programming platform, where the optimization process occurs.

Grasshopper allows for structuring a definition that interprets the basic geometry, and furthermore identifies it within the digital model's bounding elements; walls, floor, ceiling, and glazing zones. It also enables the input of an orientation, a predefined parameter as South, East, or West. The following step is then denoted with establishing parameters of the shading element. Being a core feature in Grasshopper, the process is characterized by building up associative relationships with a clear set of parameters and range for the values. This dynamic setup is then optimized, manipulating extrusion parameters in x,y,z direction with the sake of attaining the most fit extrusion and orientation of the shading element, using a carefully calculated fitness criteria to achieve the most efficient performance.

In order to achieve the intended optimization model, a series of Grasshopper plugins and components were employed, each performing a very specific task. The core component for performing the form finding process is Galapagos Evolutionary Solver. It operates by searching within a pool of solution space for the fittest solution, with regard to shading system parameters in x,y,z direction thus resulting in a specific configuration. To insure adequate performance, the process is combined with Honeybee, Ladybug, EnergyPlus, Radiance, Daysim and OpenStudio, a series of necessary components for building energy and daylight simulation. These components act as a normalizing medium for the form finding process, hence ensure adequate shading while maintaining required illumination within the space. In that sense, result from the analysis becomes the fitness factor for the optimization process. Figure 3 displays an abstract description of the process, and resulting shading element for a specific orientation, and the Grasshopper definition.

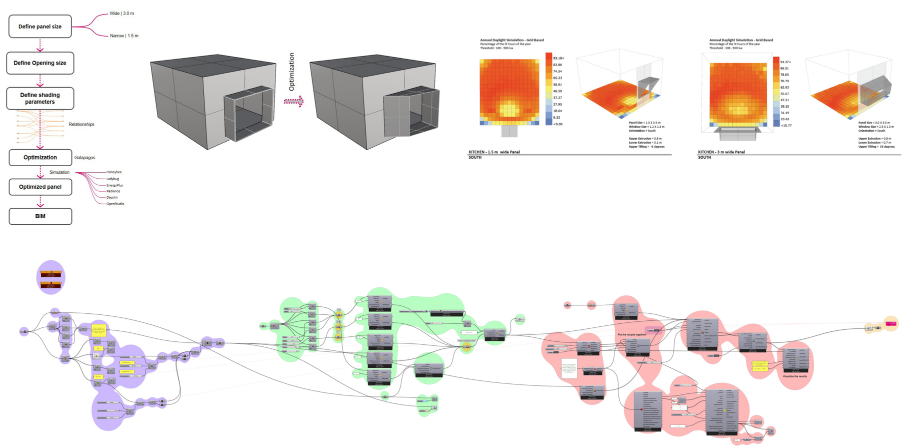

Figure 3. The optimization process combining a series of computational tools, and the outcome of optimizing an East oriented 3.0 m wide bedroom panel. Visualization of the simulation results with color codes indicating for each grid square of the layout the annual percentage of achieving optimal heat gain and lighting conditions. .

3.2. BEYOND OPTIMIZATION: EXPLORING THE ROLE OF BIM

Building Information Modeling (BIM) has proven an important role in the industrialized building industry, where it enables creating BIM parametric and customizable product families that can be shared between the manufacturer and other components' producers in the production process. Such a scheme entails standardizing the structure of object information beyond geometry, so as to include specifications for selection and use in analysis, along with material properties. Additionally, the capacity to establish a multiuser environment which enables efficient collaboration and data exchange within the design and production team. This includes the ability to export data in suitable forms for automation of the fabrication tasks using CNC machinery, based on manufacturer's capabilities, thus reducing the time required to generate technical drawings.

Within the proposed framework, there are some important capabilities that a BIM platform could support. In order to explore various possibilities, optimized panels were then exported as mesh component to Autodesk Revit, identified as a Revit panels family, and collectively fed into a comnprehensive a Panel Based Curtain System. Panels were identified under one parametric family with different types to accommodate all possibilities of orientation, function, and opening size. This mode of representation aims at developing an integrated process where panels can be interchanged within one framework, and modified according to spatial function, and orientation, resulting in a setting that is efficiently responsive to the surrounding environment. Figure 4 represents a print screen of a panel family on Revit, then how panels are applied within a house prototype based on orientation.

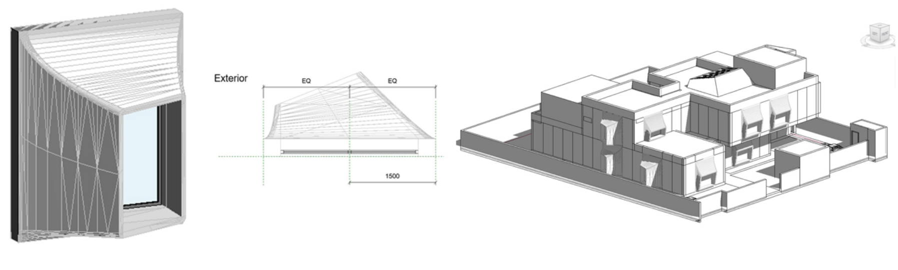

Figure 4. The panel family as it shows on Revit, 3D view and plan, then its application towards a prototype of a house in Revit.

In order to explore the practicality of such a panel system, we simulated the process to a housing prototype where various panel typology was inserted within the skin, thus demonstrate the flexibility and adaptability needed to respond to different site conditions and client requirements. This can be achieved by simply using the corresponding set of panels for each challenge, while maintaining a constant level of energy efficiency, given that all skin elements are optimized to achieve appropriate daylighting conditions throughout the year with the minimum possible heat gain. Furthermore, Revit enabled the possibility to investigate the panel materiality, where layers of concrete and insulation were introduced, with specific properties following market standards. This allowed to produce an energy model for the full house, which reflected the huge impact of micromanaging panels and material properties on the overall performance of the prototype.

4. Reflections: Towards a comprehensive model for design to production

This paper represent a research effort that aims at rethinking the design and production of precast concrete façade panels, with a specific focus on the UAE industry. We propose a digital workflow that combines a series of computational tools to design and optimize an integrated facade system. The workflow aims primarily to generate a self-shading element in response to specific contextual conditions.

Combining the power of the previously mentioned tools, the workflow allowed to develop a series of façade panels that satisfactorily respond to the research goals. To sum up the process, the application of an evolutionary solver within Grasshopper enabled manipulating the intended shading element's parameters with the aim of minimizing annual direct heat gain, while maintaining adequate lighting within the space, and according to codes. The process was connected to a set of energy simulation engines that run daylight analysis and thermal simulation to optimize window extrusion and rotation, and find the fittest solution. Initiating the process with six generic panel prototypes, the optimization following cardinal orientations; East, South East, South, South West, and West, Resulted in a catalogue of 30 variations of optimized panels, corresponding to all possible locations, functions and orientations.

While we believe the process workflow was successful on the design end, yet three drawbacks could be identified. First, the resultant of the optimization process as represented earlier in figure 6 is a surface model, with edged corners. We had to remodel the panel with smoother edges to expose the plasticity of concrete as a material, and also ease to exporting the file to Revit. Second, we did not yet have the chance to explore possibilities of fabrication. We are aware that production of resulting panels would require specific formwork and molds that would require specific production model. Lastly, the process and flow of information between Grasshopper and Revit is still very linear and in one direction, and the link is made mechanically.

In order to overcome the formerly mentioned drawbacks, we propose possible solutions that would require further exploration. On the first hand, the issue of transforming the surface model in Rhino3D into a mesh model can be introduced in the Grasshopper definition. We are currently working on restructuring the Grasshopper definition to develop the outcome of the process as a mesh rather than a surface, and perhaps automate the export-import action with better model quality results. Furthermore,another area of development with regards to the digital workflows is to introduce feedback loops to better inform both the simulation and the ptrototype BIM model.On the second hand, we anticipate the role of digital fabrication in the form of 3D Printing in the process. Recently, advancements in Additive Manufacturing techniques, such 3-Dimentional printing have been a vital area of exploration since its development in the mid-1990s. We believe that 3D printing has the potential to offer a solution for current challenges facing the concrete construction industry. Additive Manufacturing, and specifically 3D printing of concrete allows for producing highly customized building components. It is believed that these technologies could create a new era in the construction industry, one that is more adapted to specific contextual and cultural conditions.

This paper represents a critical phase of an ongoing research endeavor that aims at rethinking the precast concrete production in the UAE. The research explores possibilities for a new protocol that is focused on design to production, relying on computational design strategies in the form of energy performance simulation tools, and optimized for large format 3D printing of concrete elements. The aim is to develop an integrated approach that goes beyond current industry practices.

References

"Precast/Prestressed Concrete Institute (PCI)" : 2017. Available from <Precast/prestressedconcreteinstitute.Availableat:https://www.pci.org/PCI/Bookstore/Architectural_Resources_Bookstore.aspx> (accessed 2 Dec. 2017).

"Al Falah Community Development - Gulf Precast" : 2017. Available from <http://www.gulfprecast.ae/portfolio/al-falah-community-development/> (accessed 4 Dec 2017).

Bell, B.: 2012, Parametric precast concrete panel system, *Proceedings of ACADIA 2012 // Synthetic Digital Ecologies*, San Francisco.

Bell, B.: 2017, "Topocast | Parametric Precast" . Available from <http://topocastlab.com/portfolio/parametric-precast/> (accessed 4 Dec 2017).

Bentley, P.: 1999, *Evolutionary design by computers*, Morgan Kaufmann, San Francisco.

Caldas, L. and Norford, L.: 2002, A design optimization tool based on a genetic algorithm, *Automation in Construction*, **11 (2)**, 173-184.

Eiben,, A. and Smith, J.: 2003, *Introduction to Evolutionary Computing*, Springer, New York.

Gero, J.: 1996, Computers and Creative Design, *Proceedings of CAAD Futures 1996*, Singapore.

Krarti, D. and Tuhus-Dubrow, M.: 2010, Genetic-algorithm based approach to optimize building envelope design for residential buildings, *Building and Environment*, **45(7)**, 1574-1581.

Kumar, S.: 2011, "Precast Take the Lead" . Available from <http://www.constructionweekonline.com/article-17403-precast-takes-the-lead/> (accessed 13 Nov 2017).

O'Reilly, U. and Ramachandran, G.: 1998, A Preliminary Investigation of Evolution as a Form Design Strategy, *Proceedings of Sixth International Conference on Artificial Life*, Madison, Wisconsin, USA.

Romuald, J. and Gero, J.: 1997, A Genetic Programming Approach to the Space Layout Planning Problem, *Proceedings of CAAD Futures 1997*, Munich.