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Experimental Designs of Mass Customized Passive Single-Family Houses - Prospects and Limitations

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Abstract

The article deals with case studies of selected architectural designs of the past fifteen years the authors of which intended to rethink both the typology and the means of constructing single family houses. The analysis covers contemporary design issues such as variation, curvilinearity, customization, digital manufacturing and ecological concerns. The purpose behind the research was to establish in what way new design and production methods may contribute in creating customized passive houses for middle class families in Poland.

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Keywords: parametric modelling, digital fabrication, mass customization, passive houses, low energy houses;

1. Introduction

The development of computer technologies has led to the emergence of digital architectural design workshop based on sophisticated computational modelling techniques for generating and analysing three-dimensional geometry and advanced digital production methods. Parametric algorithmic design methodology is based on associative models of hierarchical relationship between geometry elements which were developed by scripting. The generative script allows for variations within the design logic (a change in any parameter is propagated through the whole model), embedding

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boundary conditions and optimization algorithmic procedures informed by digital analysis as well as automatically exporting production data for CNC fabrication. This makes it possible for the avant-garde designers to solve complex design problems, create innovative space and structural systems and diminish negative impact of buildings on the environment. So far the trademarks for the changes are primarily the spectacular realizations of sports, cultural and administrative buildings as well as multi-functional high-rise buildings in many places around the world. However, it is important for the quality of life of societies to exploit the potential of the new design and construction methods in context of housing demands. Statistics show that families in the EU prefer living in single family houses to living in apartments although their requirements are changing. The awakened environmental awareness coupled by the economic crisis causes that sustainability becomes an important issue when choosing a home. In developed societies the concept of freedom is associated with maximizing choices; producers of industrial goods strive for the satisfaction of individual desire through consumer-specific, unique versions of the product. Moreover, for many people brands are an important source of identity in society.

The article presents result of case studies of selected research designs of the past fifteen years, the authors of which intended for rethinking both the typology and the means of constructing single family houses. The analysis covers contemporary design issues such as variation, curvinlinaerity, continuity and customization, ecological issues, flexible manufacturing and assembly. The purpose behind the case studies was to establish how new sophisticated computational modelling techniques coupled with CNC fabrication can contribute to creating passive (low energy) houses for moderate-income families in Poland. The case studies cover: Embryological House designed by G. Lynn (1997 – 2001), Re-thinking Lascaux by moh-architects (the finalist in "1st Advanced Architecture Contest", 2006), system BURST*008 by D. Gauthier and J. Edmiston (exhibited at “Home Delivery :Fabricating the Modern Dwelling”, MoMA, 2008), the Solar House (or FabLab House) designed by team from IAAC (the people’s choice award Solar Decathlon Europe, 2012), and Parametric Design System for Passive Houses design by J. Pavlicek and M. Kaftan (work in progress).

2. Digital aesthetics

Advanced digital modelling tools revived interests in warped fluid architectural forms inspired by evolutionary biology or abstract topological concepts. Theorist P. Schumacher calls for new forms that are "parametrically malleable, differentiate gradually (at variant rates), inflect and correlate systematically".[6] The new fashion for organic houses can also be seen as a reference/return to the original shelters which were oval and domed reflecting human natural form and worldview. Rounded shapes have also a practical justification as they let for maximizing the internal volume while minimizing on the external surface. G. Lynn’s Embryological House pioneered considering the house typology as an animate highly plastic flexible and transformable entity. The design process proceeded through an interplay of direct geometric modelling in Microstation, animations in Maya and physical prototyping. Smooth transitions from the original primitive to its morph targets were generated; each frame considered a potential design solution exhibiting “a combination of the unique intricate variations of each instance and the continuous similarity of its relatives”.[4] The resulting series of houses were characterized by a unique range of domestic, spatial, functional, climatic and lifestyle constraints. Besides being an investment in “the contemporary beauty and voluptuous aesthetics of undulating surfaces” the Embryological House introduced the notion of brand identity and mass customization in the context of single family houses. (Fig. 1a)

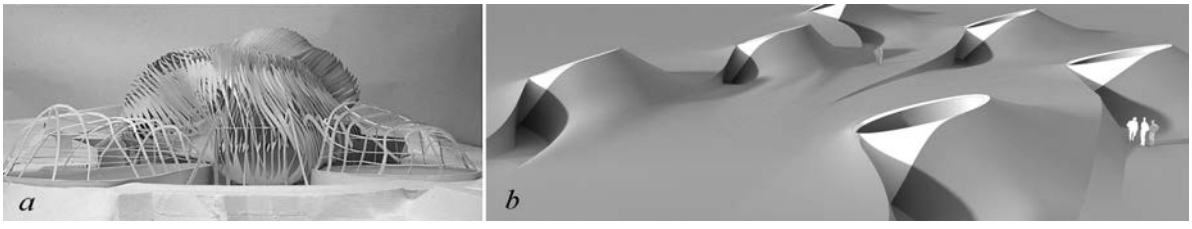

Fig. 1. (a) Instance of Embryological House, G. Lynn, 2000; (b) Re-thinking Lascaux, moh-architects, 2005.

Organic shapes also emerge from form finding processes for self-sufficient or passive houses. Rethinking Lascaux by moh architects is an example of approaching ecological awareness through custom written scripts that allow to deal creatively with energy concerns and climatic conditions. „In doing so, we did not start from a fixed typology but rather tried to use the constraints imposed as a forming tool, thereby developing highly specialized phenotypes". [12] The result is characterized by a smooth continuous undulating surfaces of building envelopes and constitute housing units that have no architectural predecessor. (Fig. 1b)

The form of The Solar House also results from parametric design strategy in which “form follows energy”. The shape of the house resembles a three legged headless body of an animal covered with scales made of solar panels. (Fig. 2a) [10]

Fig. 2. (a) The Solar House, IAAC, 2012; (b) System BURST*008, Gauthier D., J. Edmiston, 2008.

Approximation/ rationalization of doubly curved envelopes of houses and requirements in terms of ventilation and light are accounted for in novel ways by researchers. Various computational methods of free-form penalization are largely biased towards formal and aesthetic qualities and optimal production characteristics (tessellation into flat polygons or taking into account the deformability of the material). The smooth internal and external skins of Passive Houses designed by Pavlicek J., Kaftan M. is obtained by the usage of curved timber cladding and curved plaster-boards but the structural part of the hull is panelised into polyhedral surface so as there is no need for any curved members of the construction system. (Fig. 3b) [5] In Embryological House apertures, fenestration and openings are achieved by the alternative strategy of tears, shreds and offsets in the surface. By duplicating curves in the same position and then spreading the control vertices apart he created openings that coincident with the geometry of the surface. [4]

3. Digital based sustainable strategies

The ultimate goal for architects that care for the quality of the environment is to develop a housing system that requires low energy consumption for its production, for the construction of its buildings, and for the use of such buildings. Custom design tools are being developed in order to meet demands for passive solutions. [5,9,10] Re-thinking Lascaux research focused on how far space itself can help create an efficient sustainable single-housing unit without the necessity for the application of external mechanical systems (such as solar hot water, heating or cooling systems etc.) For this purpose, a parametric model (developed in Python programming language) enabling formal experiments in conjunction with a study analysing the relationship between geometry and its performance in the context of energy consumption was used. During the iterative process of form finding the shape of each unit was controlled by the climatic data of six different temperature zones (Edmonton, Stockholm, Vienna, Rome, Tunis and Riyadh). Parametrically precisely controlled deformation of houses (shifting of the hull) allow optimizing thermal performance of instances.

The Solar House is the answer from FabLab IAAC designers team for the solar powered home. Parametrical design tools (scripts) enabled working with models and climatic data. (Fig. 3a) Thanks to the incremental deformation of the section, the paraboloid hull was shaped and distorted to achieve an optimal orientation in various cities around the world (narrowing to the west, eastward widening and flattening toward the zenith of 70 degrees). The shape lets it make the most of solar rays and natural drifts (the hull is elevated off the ground) cutting with the need for artificial

heating or air conditioning. Energy is captured by a roof composed of flexible photovoltaic panels.

Elaborated by means of parametric modelling tools System BURST*008, similarly uses only passive means to optimizes micro-climate inside the house. Due to the sophisticated accordion like construction the shape of each instance of a house could be conform to specific constrains based on environment (wind and humidity), site or orientation. “The flexibility of BURST comes from literally weaving two sections together – the natural ground plane and artificial, manipulated plane. The two planes travel vertically and horizontally to compromise the ground, the floor and the walls. The weave can open, close or reshape in order to let in or keep out warming sun and cooling breezes.” [2]

Fig. 3. (a) solar analysis, (b) envelope optimization, (c) structure assembly.

At the current stage of its development Parametric Design System for passive Houses uses two VB scripts to optimize energy consumption of the house. One script calculates from CAD model descriptive data such as surface area, surface north deviation, temperature zone, window width etc. and writes them into an Excel sheet. Another script automatically transfers data into Passive House Planning Package software for energy calculation. The feedback allows for adjustments in the geometry of the building, orientation, percentage of glazing etc. until the desired values for heat demand and primary energy are achieved. (Fig. 3b)

4. Digital manufacturing

Implementation of parametric modelling techniques coupled with “file-to-factory” paradigm reflects both on the substantial freedom to generate complex forms and to invent and test new structural solutions. CNC milling, water-jet cutting, laser cutting or 3D printing guarantee precision of geometrically demanding customized building components (e.g. double curved structural elements) at an affordable price. The possibility of digital manufacturing building components seems to offer a real alternative to the current construction practices. [8] Architects who focuses especially on the file-to-factory process often deal with timber structures as the choice of wood leads to structural elements and components which are small, light and manageable. [5,7,8] The Solar House, BURST*008 and Passive House are manufactured and assembled rather than built. Prefabricated wooden construction of The Solar House consists of components that are laser cut from a 1220x1440 mm plywood sheet and could be manufactured anywhere in the world through the network of FabLabs that are in the Americas, South Africa, India, Netherlands, Norway and Spain (scale of building elements and level of technology used is selected by its availability and ease of use and maintenance). The tension structure of BURST*008 comprises of multiple interlocking plywood ribs and insulated panel skin. (Fig. 3c) More than a thousand non-identical relatively small building pieces are laser cut from Structural Insulated Panels or plywood to the exact dimensions and fit together like a 3-D puzzle (the piece’s pop into each other). Likewise, Parametric Design System for Passive Houses also allows for linking geometry data to fabrication process. Cross laminated timber was chosen due to the good performance characteristics in terms of sustainability and the possibility of customization elements through digital fabrication.

5. Discussion and conclusions

“Housing is still very much a fruitful place to look how architecture can serve society.” (Davis, 1997) Nowadays

society in developed countries challenges architects to design low-energy, passive or self-sufficient single-family homes. Innovation in architecture proceeds via the design research effort which help us think more creatively about what we can accomplish in the future. The good example would be participatory design based on web technology. [1]. Initiated by Lynn formal experiments result in the departure from the modernist idea of a house based on kit of distinct parts (that can be added or subtracted in order to customize solutions) and put in the limelight curvilinear envelopes; a spatial negotiation between program, structure, natural and synthetic environments and materials. Re-thinking Lascaux remains "pure dream that are untainted by the cost of construction, commercialism and conservatism." The Solar Houses are already available on the market - the customer can configure his/her house from different types of needs: Hut -12m^2, Refuge -24m^2, Studio -36m^2, House - 60m^2 or Villa - 96m^2).

The idea of bringing together customer specific needs, energy efficiency and affordability is currently best supported by parametric-algorithmic methodology coupled with digital fabrication. This so called “digital chain” when used to architectural design results in fast construction techniques and better performance of the building. At early stages parametric-algorithmic methodology concentrates design effort on building sophisticated models (generative scripts). It is well-founded in case of algorithmic form-finding or when dealing with aspects of mass customization of buildings components. However, defining parametric algorithmic systems poses a challenge due to the difficulty of taking into account hardly measurable and non-measurable data such as psychological comfort experienced in a domestic space with curved characteristics. [3]

It seems that for some modern society members house doesn’t necessarily have to be large, costly, immovable and last for generations. A house is not merely a shelter; it can be a way of declaring system of values or identification with certain lifestyle. This manifests itself in the “The Tiny House” movement or movable dwellings gaining on popularity in western countries. [11]

It is doubtful whether the single-family houses no matter how cleverly designed will solve housing problem globally but there is high demand for well-designed houses that middle class customer could afford in Poland. With proper interest from digital architects manufactured customized homes may become one of the options. For now, in the majority of cases houses are no longer designed individually and building industry uses pre assembly to reduce costs by standardizing solutions. The modern fashion for small eco-friendly houses indicates that there would be a market for manufactured easy assembled timber structures.

As with any new product it would imply creating domestic demand or/and appealing to the need for identity with a brand. The goal for affordable customized houses is not to industrialize but to allow any interested customer to manufacture it on locally available machinery (laser cutting and/or milling machines). The architectural education and research in Poland has yet to join ongoing research for novel solution adapted to Polish conditions.

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