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# PROPERTIES OF PARAMETRIC-ALGORITHMIC DESIGN OF RESIDENTIAL HOUSES IN THE URBAN CONTEXT

## SZCZEGÓLNOŚĆ PARAMETRYCZNO-ALGORYTMICZNEGO PROJEKTOWANIA MIEJSKICH DOMÓW MIESZKALNYCH

Abstract

Design explorations of architectural avant-garde resulted in the development of digital techniques that allow solving very complex and demanding contemporary design challenges. In the architectural discourse, the new design workshop seems to be symbolised mainly by the projects of sports facilities, cultural, administrative or multifunctional high-rise buildings. However, for the quality of society life, it is more important to exploit the potential of new methods of design and construction methods in the context of housing needs. The article presents the results of studies on the potential and limitations associated with the use of the parametric algorithmic methodology in the context of obtaining effective solutions recognising the individual needs of users and the requirements of the environmental and urban context. The research is based on case studies of experimental projects and critical analysis of the possibilities of using algorithms and design patterns with respect to residential houses.

*Keywords: parametric-algorithmic design, residential houses, personalised design solutions, participatory design*

Streszczenie

Poszukiwania projektowe awangardy architektonicznej zaowocowały rozwojem warsztatu cyfrowego umożliwiającego rozwiązywanie bardzo złożonych i wymagających współczesnych zadań/wyzwań projektowych. W architektonicznym dyskursie symbolem nowego aparatu projektowego zdają się być głównie realizacje obiektów sportowych, kulturalnych, administracyjnych czy wielofunkcyjnych wieżowców. Dla jakości życia społeczeństw ważniejsze jest wszakże wykorzystanie potencjału nowych metod projektowych i budowlanych w kontekście wymagań mieszkaniowych. Artykuł przedstawia rezultaty badań, dotyczących potencjału i ograniczeń

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związanych z wykorzystaniem metodologii parametryczno-algorytmicznej w kontekście pozyskiwania efektywnych rozwiązań uwzględniających zindywidualizowane potrzeby użytkowników, wymogi środowiskowe i kontekst urbanistyczny. W badaniach wykorzystano metodę studium przypadków eksperymentalnych projektów oraz krytyczną analizę możliwości wykorzystania algorytmów/wzorców projektowych przy projektowaniu domów mieszkalnych.

*Słowa kluczowe: projektowanie parametryczno-algorytmiczne, miejskie domy mieszkalne, personalizacja rozwiązań projektowych, projektowanie partycypacyjne*

## 1. INTRODUCTION

Housing needs of populations living in urban organisms pose a great challenge for the architectural profession in the twenty-first century. The lack of cooperative and low-cost public housing from the perspective of the less wealthy persons or those just entering the professional path is probably the main problem in Poland. In recent years, however, like in western societies, the demand for personalised products (including houses and flats) that cater for preferences and user's lifestyle is increasing. In addition, the awakened residents' ecological awareness forces housing rationalisation in the direction of energy efficiency also by seeking new building forms (not limited to the simple compact blocks with a minimised glazing in exterior walls) and adjusting the orientation of the building to the local climatic conditions[1].

In response to the increasing level of problems' difficulty in the various project areas resulting from the increase of the social and individual expectations, the avant-garde architects use general programming and scripting languages[2] to build their own customised tools. The new design workshop is based on parametric – algorithmic modelling techniques that allow to define associative dynamic digital models. These models make is possible for the designer to generate a large number of alternative solutions (the family of forms) within the specific design logic, the boundary conditions (the changes in the parameters are propagated across the entire hierarchical model) and the use of optimisation algorithms informed by the results of the digital analysis. So far, the trademarks for the changes are primarily the spectacular realisations of sports, cultural and administrative buildings as well as multifunctional high-rise buildings in many places around the world. However, the experimental studies show that parametric-algorithmic methodology is useful for the mass customisation of apartments and optimisation of housing design solutions.

The article presents the results of the research based on case studies of selected projects from the last two decades, the authors of which were heading towards the discovery of the potential of parametric-algorithmic techniques in the context of the design of residential houses. The analysis includes contemporary design dilemmas, such as individualisation, continuity and changeability, variation and sustainability. The purpose

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[1] This is reflected in the Directives of the European Parliament and of the Council of the EU and the Europe 2020 Strategy.

[2] Scripting languages are used to control specific applications, eg. AutoLISP is a scripting language AutoCAD unlike general-purpose languages (Java, C ++).

behind the case studies was to establish how new sophisticated computational modelling can contribute to creating better housing solutions within the building regulations and the economical constrains. The aim behind this research was to determine how the new sophisticated methods of digital design could contribute in achieving "delicate balance of community values, individual needs, aesthetic judgments, and technical requirement" in housing design[3].

## 2. SYSTEMS SUPPORTING HOUSING DESIGN

The key aspect of the issue of mass housing, besides the economy of construction and exploitation, is that it "bestows on its inhabitants a sense of dignity" and fulfils the cultural and psychological needs of its residents[4]. Refusing to consent for the monotony of the urban landscape and the impersonality of the houses, architects look for effective methods and tools that would allow them to generate variants of functional and formal solutions and enable prospect users to participate in the design process[5].

Attempts to create design methods based on systems theory, mathematical – logical apparatus – taking account of the conversational nature of design process have been undertaken for few decades now[6]. In the 70s of the last century, Y. Friedman presented the concept of systemic method for the design of residential structures called Flatwriter. The method would allow future residents to choose between a large number of combinatorial solutions generated by a set of predefined design rules. Friedman's intention was to enable "non-experts to make their own designs, as they are the ones who better know their own desires and, most importantly, bear the risk of failure."[7]

Also, in the 70s, G. Stingy and J. Gips developed the concept of "a shape grammar", which is mathematically formalised process for converting geometric figures[8]. This design oriented generative system that combines spatial and quantitative characteristics, constitutes the foundation for the subsequent three-dimensional architectural grammars[9]. The method consists of shape rules and a generation engine that selects and processes the rules recursively (move, scale, rotate, union, intersection etc.) starting from the initial shape. The distinctive feature of a shape grammar is that a set of a finite number of rules and shapes may generate an indefinite number of design solutions. The set of a finite number of rules and shapes allows for a very wide range of design solutions. In the context of residential buildings, shape grammar may reflect a certain typology of the houses or architect's design philosophy (in rule – based design defining of rules is a place for creativity).

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[3] S. Davis, *The Architecture of Affordable Housing*, University of California, 1997, p. 5.

[4] *Ibidem.*

[5] T. Vardouli, *Architecture –by –yourself. Early studies in computer aided participatory design*, MIT, 2011.

[6] T. Vardouli, *Architecture –by –yoursel..,op.cit.,* p. 4.

[7] A. Asanowicz, *Metody wspomagania projektowania architektury mieszkaniowej – od metod systemowych do gramatyki kształtów*, Architecture et Artibus, 1/ 2009.

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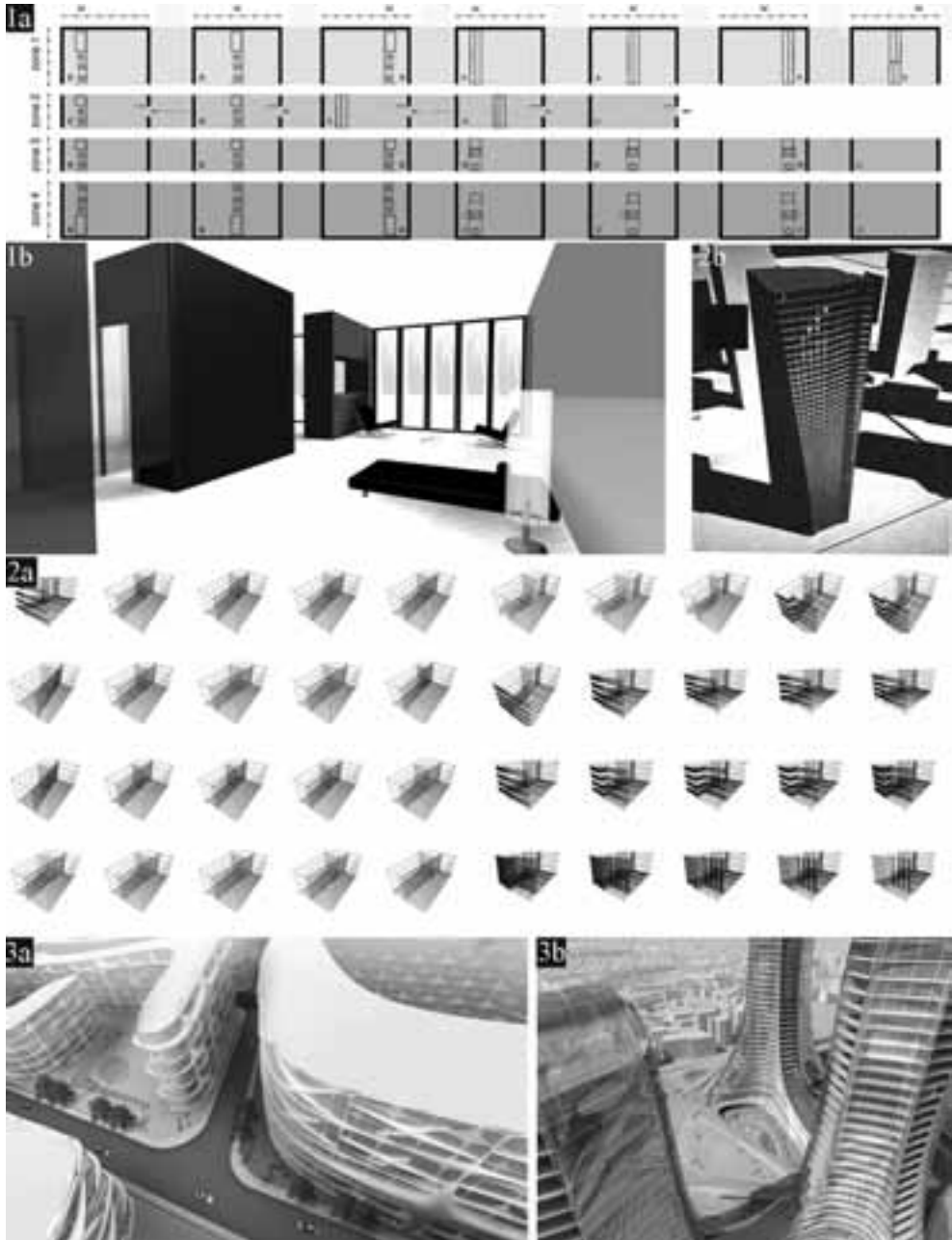
Ill. 1a. Integrated design system – matrix illustrating several possibilities for placing functional units, 1b. Rendered image of the apartment space, 2a. Space Configuration – variants of apartment layouts, 2b. Tower formation – geometry of the building, 3a. Kartal-Pendik – the articulation of the facades, 3b. Close–up of urban peaks

In the early 2000s, designer B. Colakoglu developed a shape grammar based on the analysis of the *Hayat* house type[10]. New forms of the houses generated by his grammar were a continuation of the historical formal language (classical Ottoman style), and at the same time, adapted to the modern lifestyle[11]. A different approach was adopted by J. Duarte who proposed a computer implementation of a shape grammar (using Java Expert System Shell) that codifies the design rules used by Alvaro Siza when creating settlements for Malagueira in the years 1977–1996[12].

The generative ability of shape grammars is extremely high and it allows architects to automate the design decisions that lead to the differentiation and mass customisation of flats and residential houses[13]. However, the computer implementation of shape grammars is quite complicated because it requires the solution of difficult technical problems, e.g. associated with shape recognition. In addition, the concept of a shape grammar does not include issues related to the materialisation of the project.

## 3. PARAMETRIC-ALGORITHMIC STRATEGIES for housing design

New generation systems for the housing design are based on parametric algorithmic models (which are in fact computer applications) that allow intensive usage of computing power for managing and processing vast amounts of geometric and non-geometric data. Scripts that generate geometry are sets of well-defined rules/instructions and they return "a kind of the matrix containing the entire collection of possible results, allowing the designer to move from thinking about one form to thinking about "family of forms "in which each element has both unique and shared characteristics."[14] By means of harmonising and coordinating dozens of parameters, it is possible to reach multi criteria optimisation, e.g. by adjusting the shape and the orientation of the building, the glazing to solid ratio of the skin to the requirements of sustainability, economics, aesthetics, etc. It is possible to change parameters/constraints values in search of design options within a specific generative algorithm logic and to observe the cumulative effects of introduced modifications dynamically in real time (usually it is not necessary for the processor to rerun the whole script in order to generate new instance). A very important feature of the of parametric-algorithmic methods is the possibility to incorporate in the generative procedure modules responsible for creating technical documentation, direct transfer of geometric data for rapid prototyping and production (G – code). This allows test-

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[10] *Hayat* houses were built in the 18th and 19th century in Sarajevo. An important place in the composition of the house is taken by a large covered gallery open to the garden.

[11] B. Colakogulu, *An Informal Shape Grammars for Interpolations of Traditional Bosnian Hayat Houses in a Contemporary Context*, International Conference on Generative Art, Milan, 2002, p. 15.1–15.9.

[12] J. P. Duarte, *A Discursive Grammar for Customizing Mass Housing The case of Siza's Houses at Malagueira*, 21 st eCAADe 21, 2001, p. 665–675.

[13] City Engine released by ETH Zurich in 2008, uses procedural modeling based on the new grammar shape language CGA and is widely used in urban planning, archeology and digital reconstruction of urban complexes because of its generative potential.

[14] M. Helenowska-Peschke, *Parametryczno algorytmiczne projektowanie architktury*, Wydawnictwo PG, 2014, p. 26.

ing of new structural solutions, equates the production costs of customised parts/components of the building with the production cost of standardised elements.

In 2009, M. Benros and J. Durate used a parametric strategy for the development of an advanced system for mass customised housing design, which combines design system ABC[15] with building system Kingspan[16] (using a computer program written in AutoLISP)[17]. The authors of the original ABC system did not formulate an explicit set of design rules, but made the way for the creation of variant layouts of apartments with three types of functional modules (closet, kitchen, bathroom) (Fig. 1a). The modules are prefabricated and can be customised in size and arrangement of equipment they contain. The entire space of the apartment consists of four functional zones and is free from any supporting structures. In the original ABC system, only "hard elements" in the fluid space are the functional modules located perpendicular to the opposite facades of the building and primary divisions of zones[18]. In its computer implementation, same spaces for reasons of privacy and hygiene (e.g. such as bathroom) could be also determined by walls or partitions with doors. Design rules of the integrated system are divided into categories relating to: spatial proportioning, adjacency, space confinement, structural stability and other covered by building regulations. For example, a spatial proportioning divides functional zones into a modular matrix, maintaining a hierarchy where larger functional areas (living spaces, dining room, bedroom) are in direct contact with the opposing facades, using lighting, ventilation and views, and smaller service spaces (entrance hall, cloakroom, bathroom) have a central position adjacent to the vertical communication. The space confinement rules regulate how walls and doors are automatically placed by computer program when the spaces are defined by the user. The program runs sequentially. After designing common spaces in the building (stairs, lifts), it proceeds to the design of apartments. This is done sequentially in accordance with the wishes of the user and coded design logic. Non-uniform layouts of apartments are generated in order starting from the one located on the ground floor on the left (two flats on each level). The system allows for 1,470 different apartment layouts. Structural elements are arranged by the program closed to perimeter walls and partitions in order let the space remained "fluid and to clear circulation areas of obstacles."[19] (Fig. 1b) The designers foresee two types of elements for the skin of the building: coloured glass fibre reinforced concrete panels and glass panels. The appearance of the facade is a reflection of the internal organisation thanks to the usage of a colour code associated with the functional units for the opaque panels. The design process can be monitored and unwanted solutions eliminated by the designer and the customer in the real time on the basis of a three-dimensional model generated in AutoCAD. In relation to the aforementioned shape grammars, the integrated parametric system gives smaller, but still huge set of possible

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[15] The ABC design system was developed in 1994 by M. Gauss and ACTAR for the contest for settlement in Ceuta. Its name is derived from the functional modules included in the apartment: wardrobe (es. Armario), bathroom (es. Bano) and kitchen (es. Cocina).

[16] Kingspan Building System consists of tree light systems: structural, framing and linning, and allows the construction of buildings up to six storeys.

[17] M Benros D., J. P. Durate, *An integrated system for providing mass customized housing*, Automation in Construction 18, 2009, p. 310–320.

[18] The functional unites can occupy one of the three positions in each functional zone (center, left or right) or not occur at all.

[19] M Benros D., J. P. Durate, *An integrated …*, *op.cit.*, p. 318.

housing solutions (like hundreds of thousands). However, parametric strategy allows to generate automatically technical drawings, complete lists of dimensioned construction elements of Kingspan system required to build the design, as well as 3D models for pseudo-realistic visualisation and virtual tourp.

## 4. ADVANCED PARAMETRIC TOOLS – SPACE CONFIGURATION

Currently, the emergence of graphical script editors, such as Generative Components and Grasshopper, promotes the development of parametric algorithmic methodology. Using the Generative Components, Y. Madkour and O. Neumann developed *Space Configuration,* which was a blend of design system and the construction system[20]. *Space Configuration* supported designing customised one bedroom apartments in high-rise building that takes into account contextual requirements specific to the densely built downtown Vancouver[21]. The authors focused on computational search for various apartment layouts, while perimeter walls were fixed. Their aim was to investigate the potential of parametric modelling and algorithmic techniques in the context of coordination of complex programmatic, functional and contextual relationships. In *Space Configuration,* the physical boundaries of subspaces are defined by the floors, ramps, partitions of different heights and exterior walls. Non-physical borders were established by means of lighting, sound and surface treatment. The system includes built-in rules concerning functional solutions and dimensional relationships. For example, according to these principles, a living room, kitchen and bathroom would be available from the same level, whereas a living room and bedroom will have outside exposure, a balcony would have a direct link with a living room, the minimum width of a living room would constitute 30% of the width of an apartment, etc. Y. Madkour and O. Neumann also proposed a way to translate difficult to measure or not measurable conditions, such as social factors connected with lifestyle, needs and usage preferences into parameters controlling the components of geometric model of the building. The factors correspond to accessibility, privacy, sociability, multi-functionality, number and type of occupancy and level of exposure. The requirement for energy efficiency found its expression in environmental parameters, such as the placement of the unit within the building (ground floor, middle or top floor), orientation and views. The potential residents participate in designing their apartment by determining the combination of preferred ways of their activity (work, sleep, rest, eating, celebration, exercise, etc.). The solutions are presented to prospective users in the form of virtual models. Space Configuration allowed designers to generate 65 variants of spatial configuration for the popular one-bedroom apartments on the basis of simple initial status. (Fig. 2a)

The growing importance of environmental issues in the field of architecture has spawned a new design philosophy guided by the principle "form follows energy." The results of digital analyses of the sun's path, building skin exposure, shaded area, etc. are adopted as objective forces controlling the optimisation and form finding processes. The scope of formal experimentation in the context of housing and residential units is limited by the usage requirements,

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[20] Y. Madkour, O. Neumann, *Emergent programmatic Form-ation, Parametric Deign Beyond Complex Geometries*, VDM, 2009.

[21] The basic assumptions of the concept were based on statistical data: in year 2001 single-person households in Vancouver accounted for 60%.

standards on the dimensions and proportions of the rooms, cultural background, habits, etc. Nevertheless, explorations of the geometry, which in itself could improve the building's energy efficiency, often leads to curved shapes[22]. Y. Madkour and O. Neumann chose ecology as a key aspect for the construction of a computer tool, which enables to find a form of high-rise dwelling house that respond to the particularities of physical surroundings of one of Vancouver districts. The initial shape (an extruded rectangle) is a subject to geometric deformation when exposed to a variety of often conflicting forces, which affect the overall character of the building. Issues, such as: views from the windows (depending on the gaps between adjacent buildings and location of green spaces) protection of view corridors, restrictions on height of buildings, solar exposure, orientation, have been translated into parameters and mathematical variables. Modifications applied to the whole volume of the building and changes in the contour of each floor are automatically transferred to the schedule of the apartment. As a result of the adopted from finding strategy, a V cut shape is cut into the tower face in order to maximise the façade area that faces the open view. (Fig. 2b) The method of glazing façade is the result of digital mediation between the various needs. On the one hand, designers strive to obtain maximum sun exposure and open views from the upper part of the building; on the other hand, they wanted to ensure privacy on parts of the facade directly adjoining the existing buildings and compensate the deterioration of the lighting for the lower floors. Generative Components functions for planning digital fabrication are used for approximating building surface to flat polygons and populating it automatically with façade components. Each component consisted of three horizontal panels – one glazed and two opaque. *Tower Formation* "illustrates spatial configuration and form as a result of rational design methodology", which can be adopted to building designs at other sites[23].

## 5. PARAMETRICALLY DEFINED DEEP RELATIONS

Parametric algorithmic systems can also be used to study the effect of dynamically changing local conditions/information on the processes of formation, self-organisation and functioning of urban space. Multilevel dependencies (deep relationality) defined by parametric system allow the modulation of the urban geometry to be transferred to the tectonic articulation of the buildings, ornamentation of the facades, location and articulation of the entrances and even buildings internal circulation[24]. An example of the consistent implementation of the parametric paradigm is the competition-winning Kartal-Pendik (Istanbul) master-plan by ZHA office. The design (developed in 2006) covers 550 acres and includes business district, residential and cultural institutions and recreational facilities. The urban fabric consists of two basic types of buildings (generative components) cross towers (placed on the crossing points accentuating the path network) and perimeter blocks. They provide a specific genotype that enables to generate a broad range of variation of the buildings (phenotypes). The height of the perimeter block inversely correlates with parcels area. The courtyards are converted into the internal atriums as quarters get smaller and the buildings get taller. As a result of

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[22] M. Helenowska-Peschke, *Parametryczno…op.cit.*, p. 190.

[23] Y. Madkour, Neumann O., *Emergent …, op.cit.*, p. 122.

[24] P. Schumacher, *Parametricism, A new Global Style for Architecture and Urban Design*, Architectural Design, Digital Cities, Wiley, 2009.

these rules, the block type could be *"assimilated"* to the cross-tower type. The global height regulation has been correlated with the lateral width of the overall area and "the rhythm of urban peaks indexes the rhythm of widening and narrowing of the urban stretch." The transition from the urban scale to architectural projects is done using a systematic modulation of tectonic features. The authors of the concept proposed a continuous differentiation of the facades of buildings as function of the location within the urban field, leading from the street-side to the semi private courtyard (e.g. the exterior of the blocks is given a heavier relief than the interior). (Fig. 3 ab) P. Schumacher states that "the result is an elegant, coherently differentiated city-scape that facilitates navigation through its lawful (rule-based) constitution and through the architectural accentuation of both global and local field properties."[25] Designers-imposed consequence dictates the continuation of formal language at every level of scale (urban, architectural, detail) can be considered questionable. However, the parametric algorithmic strategy allows the introduction of controlled complexity in place of monotony and/or visual chaos that characterised virtually all unregulated expansion of modern cities. Kartal-Pendik designers created a vision of a coherent whole, giving the housing area recognisable integrity.

## 6. DISCUSSION AND CONCLUSIONS

A contemporary urban dwelling house is not only a shelter, but also a product, which is supposed to meet users' individual requirements and provide them with conditions suitable for their lifestyle. It is a space, which is determining mental and physical well being of societies as well as quality and attractiveness of the urban and natural environment. "Housing is still very much a fruitful place to look how architecture can serve society."[26] Avant-garde digital designers address societal demands by means of parametric-algorithmic design techniques, which seem to be the best support for the desire to harmonise and fulfil the needs of users, energy efficiency, economy of construction. It also provides a strategy for obtaining visual attractiveness based on continuity and variation. "Aesthetically, it is the elegance of ordered complexity and the sense of seamless fluidity, akin to natural systems that constitute the hallmark of *parametricism.*"[27] The building is treated as a complicated and dynamic system falling into complex interactions between people, the same building, the urban fabric, climate and the environment. However, defining an appropriate parametric-algorithmic design system poses major technical and cognitive challenges. One of them is the need to translate immeasurable or hard to measure factors (e.g. emotional human well-being, visual lightness of structure) into mathematical variables (parameters), generative rules (algorithms) so the system returns sensible functional and formal solutions. This means that at the outset of the design process, there is a need to increase the expenditure of time and design effort due to the increased complexity of the design decisions and the need to consider a greater number of different aspects of the task[28]. In the case of residential houses, this cognitive investment could pay off at the stage of application in the form of customised solutions

[25] *Ibidem*, p. 21.
[26] S. Davis, *The Architecture ..., op.cit.*, p. 5.
[27] P. Schumacher, *Parametricism…,op.cit.*, p. 16.
[28] M. Helenowska-Peschke, *Parametryczno…, op.cit.*, p. 177.

for affordable housing. In addition, linking the design process with the requirements of building systems reduces costs and speeds up production of non-standardised structural elements. According to T. Knight, Sass L, there is a chance to develop low-cost, high-quality construction systems, which could be adapted to local cultures and communities through the implementation of a specific vernacular architectural language[29]. The use of computer systems to support the housing design also opens wide the possibility for participatory design based on the web technology. It would effectively reorganise the architect-client communication[30].

The value of innovative experimental digital designs is that it helps architects to think creatively about what we can achieve in the future in terms of new solutions in affordable housing that is both well-designed and environmentally friendly. So far, we are still waiting for the groundbreaking changes in housing design practice.

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