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DEVELOPING SOFTWARE FOR PARAMETRIC MODELLING OF BUILDINGS AND STRUCTURES FOR THE PURPOSES OF BIM

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ABSTRACT

Visualization models have accompanied the designing of buildings and structures since ancient times. Their purpose has been to give the investor an idea of what a building and different solutions applied in it would look like. To this end, models of different materials were built. But as technology progresses, it became possible to create new visualization tools and methods. Initially, drawing boards were replaced by computer programs referred to as computer-aided design (CAD), which supported the design process. They facilitated the creation of sets of lines and simple planes. With time, the designers increasingly felt the need to shape not just rectilinear but also curvilinear objects by means of computers. This is when parametrization came in handy. Parameters constitute a set of variables which can be shaped while keeping the interdependencies between them. Parametric modelling gave rise to the building information modelling (BIM). Now, a virtual model can not only be shaped in a digital environment but also enriched with different information. This way it not only has a geometry but also a structure. It was also assigned other data allowing identification of the material or technology used to erect a building or a structure. Parametrized elements of a building provide information about their number, purchase cost or physical properties. Parameters allow making quick and seamless corrections. Thanks to the application of advanced technologies, designers from different areas can keep track of these changes. Following accepting them, one can easily generate a complete set of technical documents and use them in a digital or paper format at a construction site. Parametrization makes it possible to erect buildings and structures that would have been impossible to design in the past. Today, every designer either already uses parametric modelling or will start using it sooner or later.

Key words: design tools, computer-aided design (CAD), building visualization

INTRODUCTION

A model has always been a good way of visualizing a building design. Back in the day, physical models were an indispensable working tool of every designer. However, each change of a design concept required changing its model or building a new one. The developing architectural design software market offers a wide range of possibilities of creating a documentation for a building. Its paper versions are being gradually replaced with files containing drawings, while digital visualizations are pushing out the traditional physical models. The virtual world allows to create any, even the most complex, object envisioned by a designer. Choosing different structures or colours for a new investment is not difficult, although it is connected with the necessity to apply complicated design processes. The most advanced 3D technology available today are parametric models. A parameter is a predefined feature or value. It is a factor determining a spectrum of changes with can be introduced into a model in a specific direction and with a specific

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process result in mind (Schumacher, 2009; Burry & Burry, 2010; Helenowska-Peschke, 2014).

Parametric models combine engineering and art. They allow a designer to reach out for solutions that will combine aesthetic values, functional, structural, process and material solutions, all in different scenarios. Parametric models offer much more than just visual representation of a building being designed. They also allow a smooth transition from the design to the construction stage (Helenowska-Peschke, 2012; Januszkiewicz, 2016).

The building information modelling (BIM) is the most popular parametric model technology used in construction. Models created using BIM accurately reflect the shape of the designed building in the virtual world. They provide plenty of information not only about the geometry of a building, but also about the applied technology, as well as the respective materials, costs, physical properties etc. These elements are also considered to constitute parameters. Creating such a virtual model encourages interaction between designers from different disciplines. Parametrizing the building geometry stimulates interaction with other elements of an object being designed. A parametrized model can be easily developed, shaped and changed. Each designer working on it gets to introduce changes to it and immediately see their effect. For example, they get to see how adding more walls will affect the layout of the systems, the load-bearing capacity of the structural elements, the appearance of a building or its costs (Teicholz, Sacks, Eastman & Liston, 2008; Hudson, 2010).

PARAMETRIC MODELLING IN LITERATURE

As its name implies, parametric modelling focuses on the importance of the selection and management of parametric values. Its purpose is to seek versions of a design based on a logic specified by means of an algorithm. According to Lars Hasselgren (one of the founders of SmartGeometry Group), the idea behind parametric designing is not to design a building but "a system that will design it" (Helenowska-Peschke, 2014). Branko Kolarevic believes that parametric modelling changes the nature of the design process, as rather than design a specific shape of a building, a designer determines a set of rules in the form of a set of parametric equations (Kolarevic, 2003). Using computers for the purposes of parametrization is conducive to better management and processing a multitude of information. This primarily regards the limitations and relationships between the many factors needed to be taken into consideration when designing a building. Ben van Berkel and Caroline Bos, in turn, define parametric modelling as a design method organizing a design into a spatial model whose elements are described by means of equations ensuring coordination of changes to its components (Sollazzo, 2010).

A computer program is a parametric system and constitutes a personalized design tool. It contains data related to spatial interdependencies, the rights to inherit given geometric features and the rules of creation of further levels of spatial relations. Parameters are clearly related to the resulting geometry and their values can be manipulated directly. This way, a generated shape can be modified multiple times by the designer's system, until it finally meets their expectations. A parametric system allows using the advantages of the script techniques to create a fully interactive environment. Designers get to determine the dynamic interdependencies between parameters and, consequently, control a design and interact with it (Gane, 2004; Hudson, 2009; Madkour & Neumann, 2010).

Creation of visualization software

In the past, creating a model of a building required using a sculpting technique. A model was formed by adding or removing material, usually stone, wood or clay. Initially, computer graphics allowed only using point coordinates on a plane. The need to model more complex shapes has resulted in the development of novel, parametric geometric definitions and software which would support the process of their transformation (Teresko, 1993; Assasi, 2019).

The foundations for building an interactive digital model were laid in 1962 by Ivan E. Sutherland, who created the program called Sketchpad. It was the first attempt at creating a parametrization tool. The drawback of that solution was that the system could only be used on a specially designed computer located in a lab at the Massachusetts Institute Technology (Sutherland, 1963; Helenowska-Peschke, 2014). The visualization offered by the program boiled down to displaying just the edges of solids. The tool proved productive in the case of polyhedrons but was ineffective when it came to curvilinear surfaces (Słyk, 2018).

This type of shapes was sought by engineers from the automotive industry. Few years later, it was them who developed a new, flexible definition of the curve. Their goal was to achieve as precise parametrization as possible. Bézier curves were determined using control polylines, while Bézier surfaces, constituting their extension – by means of control grids. This way, the interaction between the user and the computer was simplified. Modelling surface required defining a limited number of points and functions affecting the final surface shape. After shifting the control points, the computer generated a curve or surface again. Meanwhile, experiments regarding using B-splines were conducted. These actions, combined with the research conducted in the industry, bore fruit in the form of a standard of geometric shapes which are commonly used today in digital modelling as non-uniform rational basis-spline (NURBS). Through the automotive industry and then universal engineering design programs, they finally made it to architects' studios. The power of NURBS lies in the unique features of this algorithmic concept. They can be used to create a variety of forms: lines, flat surfaces, polyhedrons, as well as conic sections and saddle surfaces. In addition, NURBS is intuitive and does not require broad mathematical knowledge (Słyk, 2018).

The beginnings of the computer-aided parametric designing

In 1982, the Canadian company Autodesk released a software named AutoCAD R1. A year later, Adra Systems launched CADRA 2D, and in 1984 Bentley Systems launched MicroStation. The first CAD programs replaced the drawing board, improved the precision and speed of making drawings and allowed multiple editing and printing of drawings.

In 1987, Parametric Technology Corporation launched a CAD-type parametric system based directly on the idea of the creator of Sketchpad. The Pro/ENGINEER system was based on embedding data in the basic shapes. Its operation was based on using parameters (numerical values of the features defining the interdependencies between elements), equations and logical rules to define and control the forms and the corresponding properties. Objects were positioned by means of parameters and restrictions. Changing the dimensions or the position of an element would have caused self-modification of the resulting geometry. Consequently, creating a coherent design documentation was significantly improved (Helenowska--Peschke, 2014).

Based on the foundations laid by Pro/ENGINEER, in 1993, Dassault Systčms incorporated many of the parametric functions into the CATIA v. 4 software (Weisberg, 2008).

In 2004, CATIA v. 5 was developed, featuring tools dedicated for architects to facilitate the creation of geometrically complex architectural designs. The program primarily rationalized objects with complicated geometry by enabling designers to modify the parameters and equations defining the geometry.

However, only a few studios created projects geometrically complex enough to justify the program use. Most architects used computers simply to create 2D drawings. After 2000, some architects became interested in specialist 3D modelling software, such as Revit or ArchiCAD (Davis, 2013; Pawłowicz, 2016; Chatzivasileiadi, Wardhana, Jabi, Aish & Lannon, 2018).

Scripts – design automation

Parametric modelling is also applied in designing by means of a script interface. It allows designers to write a code, thus automating specific parts of the software. Already in 1982, the creators of AutoCAD realised that introduction of scripts would allow to avoid cost of programming for specific clients (Davis, 2013).

By foreseeing the needs of designers, commercial software developers made available interfaces for writing text scripts which allowed to extend the possibilities of these applications. Consequently, AutoCAD was supplemented by the AutoLISP code, Visual Digital Project with Visual Basic, ArchiCAD with the GDL code, Revit and Rhinoceros by Visual Basic & Python. Script languages initiated innovations in designing and enabled to overcome the limitations of the commercial programs and to create non-standard architecture. However, they remained the domain of IT people cooperating with design teams (Słyk, 2018).

In 1982, Mark Burry decided to create a parametric model of a hyperbole for the Sagrada Familia church. To this end, he applied a script allowing him to develop such function in AutoCAD by himself. His script featured three input parameters – points: initial, minimum and asymptotic. These parameters were subjected to numerous equations (in the AutoLISP code) to generate a hyperbole. A script with its input parameters, functions and results is an archetype of the mathematical definition of parametricity (Burry, 2007, 2011).

Creation of BIM

Parametric thinking in designing may be understood as a process of isolating operations and input data from a specific task. This approach gave rise to the BIM technology. These programs use parametric equations to automate changes, unlike the typical parametric modelling software such as Pro/ENGINEER, CATIA or Sketchpad, where parametric interdependencies are hidden and cannot be modified directly by the user. After Revit acquired Autodesk, the previous rhetoric related to parametric modelling was given up. This approach to designing is referred to as BIM. Its name aims at differentiating it from parametric modelling by stressing the differences between managing information (parameters) and the model itself. Consequently, most designers will never come across parametric modelling software such as Digital Project or Pro/ENGINEER. They will probably frequently use parametric equations, to a certain extent, to shape their buildings, without even realizing it.

However, there are those who will organize their projects into script chains. A code-based BMI model may improve the flexibility, productivity and coordination between disciplines, especially with regard to complex and long-lasting problems. In big and complex BIM projects the code may react to constantly evolving changes to a project much quicker and much more easily than other, comparable software systems (Park & Holt; 2010).

ANALYSIS OF DIFFERENCES BETWEEN PARTICULAR SYSTEMS

Comparing parametric applications and CAD tools

Firstly, one should discuss the issue of setting limits, which is the main factor differentiating between the parametric systems and the CAD software. In the past, a designer would have to transfer the parameters set by them to a computer screen. Presently, most parameters are set in the program and are used automatically without thinking much. Some of the limitations can also be defined and grouped, e.g. division into zones. Parametric applications memorize the set limitations. In the case of the traditional CAD approach, designers are limited only by their creativity and skills.

Parametric programs enable designers to determine interdependencies between objects, which is not possible with the traditional CAD tools. They also offer a higher level of management of all drawings in a project, such as views, sections and façades, while in the traditional CADs all drawings have to be prepared separately. Woodbury claims that with the conventional designing tools creating a model was easy but making changes to it was difficult and required a lot of effort. Removing a part was also easy as particular elements were independent of each other. Parametric design requires a designer to focus on a logic that combines individual elements of a project. This process may be time-consuming, but at least it saves the trouble of introducing changes to drawings (Woodbury, 2010).

The CAD software can be enriched with parametrized elements by applying scripts. By inputting their own codes, each designer can create any curve, plane or solid in their drawing tool. This certainly facilitates and improves works, as well as brings interesting effects.

Parametric modelling versus BIM

Most designers believe that the parametric design and BIM are synonymous or have the same origins. In reality, although the two approaches are parameter-based, two important factors make them different.

The first one is related to the ability to create scripts, which is offered by all parametric programs, and which allows a designer to have something of a dialogue with a computer program. In contrast, the BIM structure is rigid and prevents designers from enjoying the freedom of form shaping that is offered by parametric tools. BIM applications do not offer the possibility of working with scripts, which again limits the designers' choice to standard commands and procedures (Pawłowicz & Nakielska, 2018).

Most of the parametric programs have been developed as a result of searching for new forms while focusing on an innovative approach to design, whereas BIM is more about increasing the effectiveness of designing. BIM is a very good tool from the commercial point of view, as it allows designers to model a design and make it available. After introducing a change, all drawings are updated, which in a way resembles parametric programs. However, parametric environments are typically used to search for a form or generate it, rather than to create a database of information on elements of a design.

In a sense, BIM is a "construction tool", rather than an "architectural tool". It gets together all creators of a design to facilitate their mutual cooperation. In other words, BIM is a tool for connecting different disciplines (construction), while the parametric systems aim more at facilitating the process of searching for a form (designers). A recent BIM research shows, however, that solving problems together – the underlying idea behind BIM – does not really work. Although BIM tries to form a stronger technological bond between the participants of a project, they remain divided from the organizational point of view, frequently experiencing a lack of quick access to key information (Neff, Fiore-Silvast & Dossick, 2010).

SUMMARY AND CONCLUSIONS

This study discusses briefly the development of the market and the demand for the parametric building design. It explains that the possibility to design complex geometric shapes and their aesthetic values is not the most important benefit resulting from the parametric approach. The key argument for its application is the optimization of design solutions. Describing thousands of components by means of a few parameters allows generating numerous versions of a model and eventually choosing the one that will ultimately meet the needs of the designer and the investor. The parametric model is no longer just a tool for representing the designed geometry, but a mathematical description of a design process, updated as a design progress.

The BIM models are an example of coordination of an entire process of creating a design. The built-in parametrization helps create a building meeting the investor's needs in terms of its functionality and structure. Thanks to parameters, a building can have an interesting shape, satisfying the aesthetic ambitions of the investor. Assigning features and properties to each component of a BIM-designed building results in it being the source of any information e.g. about its costs, construction schedule, maintenance and management.

The challenge is to train the engineers, taking into account the changing nature of the designer's job and their needs. One cannot expect designers to have professional programming knowledge, however, it should be big enough to enable them to communicate with programmers. Schools should promote platforms encouraging innovation and effectiveness of design, as well as solving problems by means of computers rather than by increasing effectiveness of drawing or modelling.

Authors' contributions

Concept of work: J.P.; methodology: J.P.; data validation: J.P., M.J.; formal analysis: J.P., M.J.; research: J.P., M.J.; resources: J.P., M.J.; compilation and processing of data: J.P., M.J.; preparation of the draft version of the article: J.P., M.J.; editing and proofreading of the article: J.P., M.J.; visualization and graphic design: J.P., M.J.; supervision: J.P.

All authors are familiar with the version of the manuscript intended for publication.

REFERENCES

Assasi, R. (2019). Parametric Design, A Historical and Theoretical Overview. In M. Asefi & M. Gorgolewski (Eds.), *Proceedings of the International Conference on Emerging Technologies in Architectural Design (ICETAD2019)*. Toronto: Department of Architectural Science of Ryerson University.

Burry, M. (2007). Innovative Aspects of the Colònia Güell Chapel Project. In M. Burry (Ed.), *Gaudi Unseen: Completing the Sagrada Familia* (pp. 59–61). Berlin: Jovis.

Burry, M. (2011). *Scripting Cultures: Architectural Design and Programming.* Chichester, UK: Wiley.

Burry, J. & Burry, M. (2010). *The New Mathematics of Architecture.* London: Thames & Hudson.

Chatzivasileiadi, A., Wardhana, N. M., Jabi, W., Aish, R. & Lannon, S. (2018). Characteristics of 3D Solid Modeling Software Libraries for Non-Manifold Modeling. *Computer Aided-Design and Applications*, *16* (3), 496–518. https://doi.org/10.14733/cadaps.2019.496-518

Davis, D. (2013). *Modelled on Software Engineering: Flexible Parametric Models on the Practice of Architecture* (PhD thesis). Royal Melbourne Institute of Technology, Melbourne. Retrieved from https://www.danieldavis.com/papers/danieldavis_thesis.pdf

Gane, V. (2004). *Parametric Design: A Paradigm Shift*? (PhD thesis). Massachusetts Institute of Technology, Cambridge, MA. Retrieved from https://dspace.mit.edu/bitstream/handle/1721.1/28478/57138114-MIT.pdf

Helenowska-Peschke, M. (2012). Applying generative modelling tools to explore architectural forms. *Journal of Polish Society for Geometry and Engineering Graphics*, *23*, 43–49.

Helenowska-Peschke, M. (2014). *Parametryczno-algorytmiczne projektowanie architektury*. Gdańsk: Wydawnictwo Politechniki Gdańskiej.

Hudson, R. (2009). Parametric Development of Problem Descriptions. *International Journal of Architectural Computing*, *7* (2), 199–216. https://doi.org/10.1260/147807709788921958

Hudson, R. (2010). *Strategies for Parametric Design in Architecture: An application of practice led research* (PhD thesis). University of Bath, Bath. Retrieved from https://researchportal.bath.ac.uk/files/187941972/RHudson-EThesis.pdf

Januszkiewicz, K. (2016). Projektowanie parametryczne oraz parametryczne narzędzia cyfrowe w projektowaniu architektonicznym. *Architecturae et Artibus*, *8* (3), 43–60.

Kolarevic, B. (2003). *Architecture in the Digital Age. Design and Manufacturing*. New York: Spoon Press.

Madkour, Y. & Neumann, O. (2010). *Emergent Programmatic Form-ation: Parametric Design Beyond Complex Geometries.* Riga: VDM Verlag Dr. Müller.

Neff, G., Fiore-Silvast, B. & Dossick, C. S. (2010). A Case Study of the Failure of Digital Communication to Cross Knowledge Boundaries in Virtual Construction. *Information Communication & Society*, *13* (4), 556–573. https://doi.org/10.1080/13691181003645970

Park, K. & Holt, N. (2010). Parametric Design Process of a Complex Building in Practice Using Programmed Code as Master Model. *International Journal of Architectural Computing*, *8* (3), 359–376. https://doi.org/10.1260/1478-0771.8.3.359

Pawłowicz, J. A. (2016). Wykorzystanie komputerowych programów inżynierskich do modelowania obiektów z danych skaningowych 3D. In W. Jagodziński & B. Kmieciak (Eds.), *Człowiek w społeczeństwie. Wybrane aspekty badawcze. Bezpieczeństwo – zdrowie – edukacja* (pp. 131–137). Katowice: Wydawnictwo Naukowe Sophia.

Pawłowicz, J. A. & Nakielska, M. (2018). Modelowanie budynków z danych skaningowych 3D na potrzeby Building Information Modeling. *Materiały Budowlane*, *10*, 110–112. https://doi.org/10.15199/33.2018.10.34

Schumacher, P. (2009). Parametricism: A New Global Style for Architecture and Urban Design. *Architectural Design*, *79* (4), 14–23. Retrieved from https://doi.org/10.1002/ad.912

Sollazzo, A. (2011). *Digital Van Berkel: diagrams, processes, models of UNStudio.* English transl. R. Guarda. Rome: Edilstampa.

Sutherland, I. E. (1963). *Sketchpad. A Man-Machine Graphical Communication System* (PhD thesis). Massachusetts Institute of Technology, Cambridge, MA. http://hdl.handle.net/1721.1/14979

Słyk, J. (2018). *Modele architektoniczne*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.

Teicholz, P., Sacks, R., Eastman, C. & Liston, K. (2008). *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors.* Hoboken, NJ: Wiley & Sons.

Teresko, J. (1993, December 20). Parametric Technology Corp.: Changing the way Products are Designed. *IndustryWeek*.

Weisberg, D. E. (2008). *The Engineering Design Revolution: The People, Companies and Computer Systems That Changed Forever the Practice of Engineering.* Cyon Research Corporation. Retrieved from https://www.cadhistory.net/

Woodbury, R. (2010). *Elements of Parametric Design*. Abingdon-on-Thames–New York–Toronto: Routledge.

Pawłowicz, J. A., Jurczak, M. A. (2021). Developing software for parametric modelling of buildings and structures for the purposes of BIM. *Acta Sci. Pol. Architectura*, *20* (1), 87–93. doi: 10.22630/ASPA.2021.20.1.9

ROZWÓJ OPROGRAMOWANIA W KIERUNKU PARAMETRYCZNEGO MODELOWANIA OBIEKTÓW BUDOWLANYCH NA POTRZEBY BIM

STRESZCZENIE

Modele wizualizujące projektowany obiekt powstawały od zarania dziejów. Ich zadaniem było pokazanie inwestorowi wyglądu i rozwiązań zastosowanych w tworzonym budynku. Kiedyś odbywało się to przez budowanie makiet z różnych materiałów. Postęp technologiczny pozwolił jednak na tworzenie nowych narzędzi i metod wizualizacji. Programy komputerowe na początku zastępowały deski kreślarskie i wspomagały proces projektowania – CAD (ang. *computer-aided design*). Ułatwiały tworzenie zestawów linii i prostych płaszczyzn. Z biegiem czasu projektanci odczuli potrzebę kształtowania nie tylko prostych, ale też krzywoliniowych obiektów za pomocą komputerów, w czym pomocne było wykorzystanie parametryzacji. Parametry stanowiły zbiór zmiennych, które można było kształtować z zachowaniem różnych wzajemnych zależności. Z modelowania parametrycznego narodziła się technologia BIM (ang. *building information modelling*). Wirtualny obiekt mógł być kształtowany w cyfrowym środowisku, a także wzbogacany o różne informacje, dzięki czemu miał nie tylko geometrię i strukturę. Przypisane były do niego również inne dane pozwalające na identyfikację materiału czy technologii wykorzystanej do budowy. Sparametryzowane elementy budynku informują o ich ilości, koszcie zakupu czy właściwościach fizycznych. Dzięki parametrom w szybki i bezproblemowy sposób można nanieść poprawki. Zaawansowane technologie komputerowe umożliwiają projektantom różnych specjalności śledzenie tych zmian na bieżąco. Po ich zaakceptowaniu można łatwo wygenerować komplet dokumentacji budowlanej i korzystać z niej w postaci cyfrowej lub papierowej na budowie. Parametryzacja doprowadziła do powstawania obiektów, które kiedyś byłyby niemożliwe do zaprojektowania. Obecnie każdy projektant ma do czynienia z modelowaniem parametrycznym lub wkrótce na pewno się z tym zetknie.

Słowa kluczowe: narzędzia projektowe, komputerowe wspomaganie projektowania (CAD), wizualizacja budynku