Digital technologies in architectural design, verification and representation

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***Abstract*— Digital technologies in the process of architectural design, verification and representation provide innovative tools for the creation of a time-spatial model of the construction as well as the simulation, analytical and evaluation methods of proposed structures from the viewpoint of assessing natural, technical, ecological and socio-economic impacts. In the case of parametric procedural modeling, the specified parameters directly generate spatial structure. Current comprehensive Building Information Modeling systems integrate the creation tools, tools for static and load testing, energy performance and facility management. They provide the ability to parameterize the design and validate it not only in the animation but in virtual reality as well. The methods of augmented reality mediate almost the real perception of the object proposed in the process before its physical construction. The research encompasses the actual trends within this dynamic field, including ethical and legal contexts and the overview of the historical background of its application in the educational process at the Faculty of Architecture Slovak University of Technology in Bratislava.**

Keywords-* *Building Information Modeling, architectural design, verification and presentation

I. Introduction

Modern digital technologies represent a revolutionary and maximally dynamic global phenomenon that greatly affects all areas of human activity. Over the last decades, many new tools and methods of work have been established, without which it would be hard to imagine present life and work styles. Many of them represent great challenge and the prospect of further research and applications. The publication focuses on tools which support digital creation and representation professionally related to architecture, landscape planning and civil engineering.

II. Building information modeling

According to various sources [1], [2], Building Information Modeling (BIM) represents the actual and future complex technology systems for architecture and civil engineering (AEC) industry, furthermore it is not only the system, rather it is the working method. Managing construction production from building design through building life cycle and Facility Management (FM) can make a significant contribution to increasing the efficiency and sustainability of the entire process. BIM provides the potential for a virtual building information model used by architects, engineers and building specialists, developers, investors, owners, each add their specific know-how to a common information model, specified as „an intelligent simulation of architecture“ [3]. The application greatly reduces the loss of information during transmission. In order to make BIM useful for facility managers or owners, project teams should define in early stages which FM information they need to include in their BIM models [4]. Successful implementation requires well predefined process of collaboration, the Level of Detail (LoD) applied in the process and a well executed interoperability plan [5] for exchanging data between BIM actors. When all participants in the construction process work on a virtual information model from concept to implementation, changes are operationally coordinated throughout the project. It also prevents errors at various stages of building construction, and allows detailed visualizations of each part of the building. BIM applies the sharing of teamwork on the virtual building model and the distant collaboration using Cloud solutions and coordinated management of teamwork, where the hierarchy of individual roles and accesses are established.

A. BIM revolutionary approach

BIM contains object-oriented parametric modeling elements. The process of creating project documentation of urban and architectural structures is in this case maximally supported by the creation of object elements (such as walls, columns, slabs, trusses, stairs, ...) by which specific parameters are entered (height, thickness, interdependence, material, ...). In case of changes of a particular parameter (floor height, material,...), which occurs very often in the architectural design and project processing, it is very easy and quick to modify the parameter, depending on which all objects defined in this way are modified in all views (floor plans, sections, views, 3D perspectives) as well as in specifications of materials and costs.

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Fig.1.BIM model of residential building, student:J.Morong, teacher:M.Malovany, FA STU Bratislava, archive of authors.

BIM is a computer model that contains all the information about a building, including its geographic location, building elements, life cycle, and its proper use significantly contributes to sustainability in architectural and urban design. It contains spatial and environmental tools for the optimization of energy calculations, verifies the physical parameters of the building (lighting, glare, noise and wind loads, ...) in the design process. Many BIM systems include multi-professional digital creation tools that connect all professions participating in the creation of project documentation (designers, architects, civil engineers, HVAC specialists, structural engineers, …). BIM makes it possible to verify the load-bearing structures of the building on the basis of the proposed shape geometry and simulation of the load conditions of the building operation. BIM systems include HVAC tools or applications for heating, ventilation, and air conditioning for digital design, simulation and verification of building heating, ventilation and air conditioning, anti-collision analysis. BIM is thus a complex database. This database uses a 3D model to organize individual building elements. In the case of the application of a digital library of building elements and materials directly from the manufacturers, indicating their parameters and costs, BIM can form a very comprehensive basis for price calculations and listings of building materials.

B. Green building modeling

From January 2019 all new buildings used or owned by public authorities must meet the condition of nearly zero energy performance (Directive 2010/31/EU on the energy performance of buildings). BIM Green Procurement (GP) thus represents important tool to achieve environmental policy goals [6] with the regards of energy performance and utilization of local sources. BIM itself applies objects which if provided with the information on their environmental impact can simulate the best solution still within the virtual model. It is as well important to involve the information about the project site [7], with the climatic location and surrounding urban structure influencing the insulation gains or losts.

C. BIM data management

The BIM information model consists of graphical information represented by a 3D model, non-graphical information that specifies the physical and functional features of the building elements, and finally the building documentation, such as contracts, records ... Thus all complex information about the building are completed in one database, called as well the Common Data Environment (CDE), which is used by multidisciplinary teams in a managed process. This has defined roles and approaches as well as types of information in progress: work in progress, shared, published and archived information. A key moment for shared collaboration is the reliable and efficient exchange of data and information.

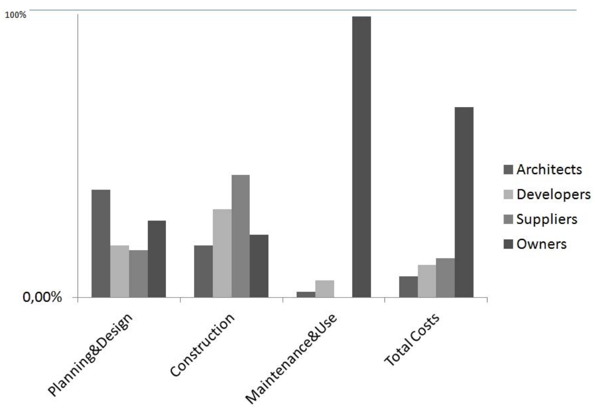
BIM usage limits are in real interoperability and the ability to integrate different input data from all actors in the process, which in the past has caused significant problems for effective cooperation [8]. That is why the Industry Foundation Classes (IFC), a standardized exchange format, certified, developed and updated by buildingSMART alliance has been developed [9]. IFC data format is designed to digitally express construction and industrial data. It is a neutral and open specification that is not subject to any commercial entity and is freely available. It is an object-based file format commonly used for BIM systems. The structure specifies the attributes of data exchange in coherence with ISO 10303 Industrial automation systems and integration. The common data scheme allows data to be used and exchanged between different software applications, and this schema must include information from all disciplines involved in the building throughout its life cycle - from design, construction, use, revitalization and possibly demolition. For the communication and model control without the full model sharing the specific exchange format was created – Building Collaboration Format (BCF).

Meanwhile, a significant limit to the wider extension of BIM design is the absence of building libraries of building components from manufacturers, as well as BIM management guidelines at national level [10]. As well many developers do not perceive the significant benefits of BIM systems for building operation and facility management.

D. BIM Return of Investment

Besides the 3D geometry the information model integrates the 4D - time dimension, embracing time and all life cycle stages of the building – from the design process, construction procedures, through building operation and possible demolition. With the connection to the spatial arrangement of building objects it is possible to present the financial costingness of a particular stage of construction, presented as 5D. As is obvious from more sources [10], [11] the most costly stage of building life cycle management, also referred to as 6D in BIM, is the stage of the building operation - up to 80%.

A study realized in U.S.A. [12] proved that the biggest asset in Return of Investment (RoI) was achieved not in the design and planning phase, but significantly in the building use and maintenance phase (graph 1). It is therefore necessary to educate the professional public within this context. According to EU analyzes [13] up to 35% of construction costs are loosing due to uncoordinated cooperation, weak digitalization and low BIM implementation, which varies across the continents, from 73% in North America, through 55,9% in Europe, to only 46,4% in Asia [14].



Graph 1. shows the cost distributed within various actors and life cycle of the building, V.Joklova.

III. PROCEDURAL MODELING IN ARCHITECTURE AND LANSCAPE PLANNING

BIM includes tools for creating urban structures, drawings, and calculations, and can actually be used as simpler Geographical Information System (GIS). GIS are systems that collect, store, organize, analyze, manage and present all types of geographic data for decision-making, creative and evaluation processes in the territory [15]. The tendencies of integration of BIM and GIS at various stages of construction have been frequent recently, newertheless both use different geometry (Boundary represented B-Rep in GIS; and Constructive Solid Geometry in BIM), exchange formats, different modeling approaches; and GIS is, unlike BIM, always strictly georeferenced [10]. Both systems have the tools for procedural modeling, applying process modeler, Grass and Python plugins, which is a popular way to create virtual architectures because it can generate varying content through simple parameter changes [16]. For example, it is often used in facade design while assessing the model in terms of functionality, insulation, lighting and aesthetic performance. It is also widely used in the process of various urban analyzes applicable in GIS (figure 2).

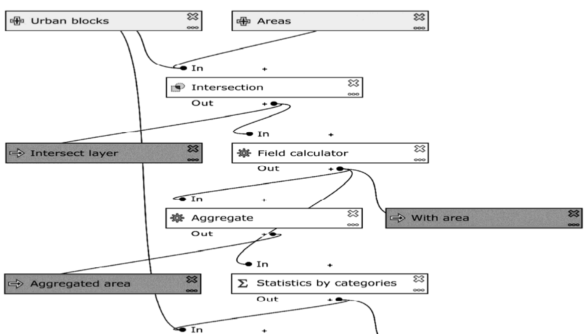
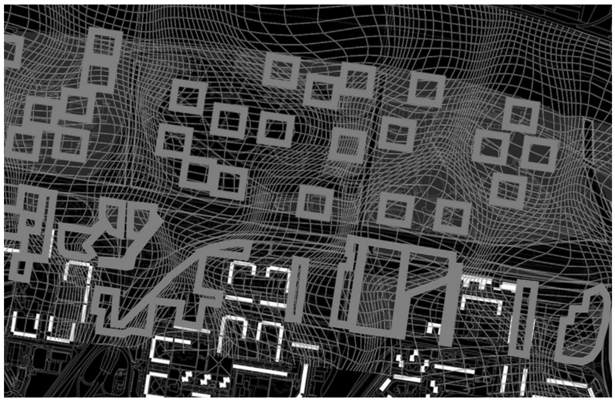


Fig.2.QGIS processing modeler designed for calculation of areas in urban maps, archive of authors.

Procedural or parametric modeling is the process of creating complex spatial structures that are modeled on defined creative intentions, variable functions, and parameters, using scripting tools. By changing the relationships - design parameters - the resulting shapes can be quickly generated and modified. It is a rather demanding process of creating architectural-urban structures, so special parametric systems have been developed that do not require a professional scripting language (Grasshopper).



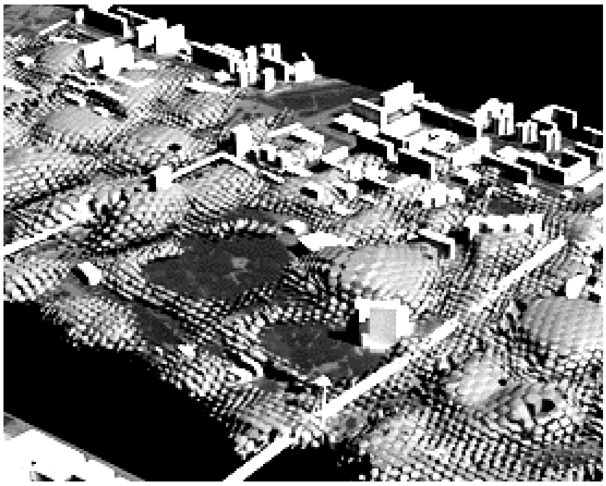


Fig.3.,4. Procedural modeling of urban structures, FA STU Bratislava, students: A.Grek,L.Oriskova, teacher:V.Joklova, archive of authors.

IV. NANOTECHNOLOGY GENERATED ARCHITECTURE

The visionary philosophy of procedural modeling represents the digitally and nanotechnology generated architecture modification in the form of changing the spatial organization of a basic architectural mass based on the needs of users. The main principle of research in nanotechnology was precisely manipulating atoms and molecules [17] for fabrication of macro scale products what afterwards was generalized by manipulation of matter with dimension sized from 1-100 nanometers. This direct manipulation with atoms can provide materials with many times better properties, which can be used in architecture and building industries as well. Nanotechnology is helping to considerably improve, even revolutionize, many technology and industry sectors: information technology, homeland security, medicine, transportation, energy, food safety, and environmental science. However, more research studies highlight as well the negative impacts of nanotechnologies on human health [18] and the environment [19] and require common global nanomaterial research and applications strategies [20]. Nanotechnology raises many issues as any new technology, including concerns about the toxicity for humans and negative environmental impact of nanomaterials.

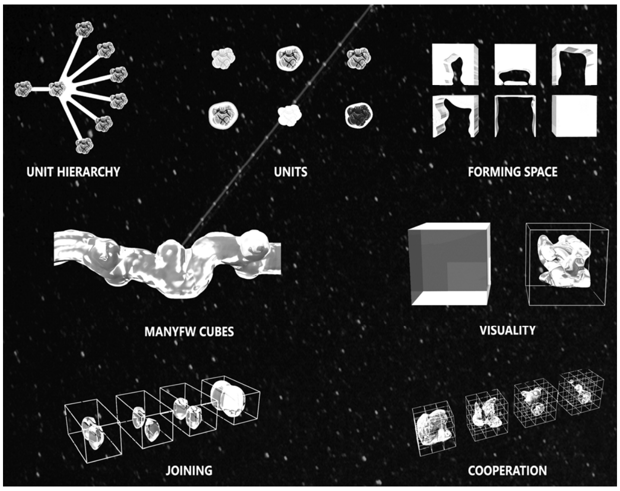


Fig.5. Nanotechnology generated architecture, FA STU Bratislava, student: I.Kulifaj, teacher:M.Uhrik, archive of authors

Nanotechnology brings different views how to create space and its borders by materiality but still not in the scale big enough to reshape cities or architecture as major idea. The application of nanotechnology research in the process of architectural and landscape planning and space creation opens new, highly futuristic exploration models, which create a consequent need for an ethical, aesthetic, psychological and construction examination of the issue feasibility. The concept presented in the student design of architectural mass (figure 5) supposes to be able to react with its users and thus can provide the infinity options to create and modify architectural space. The modular boxes are filled with nanotechnology mass which can form interior space. Cubes are added to each other to form required structure and communicate together. As the mass forms the space, structure further develops, forming thus another framework volume to existing space. In this case the psychologic consequences how would human react in "no limit" space is very interesting. And the most important is the question how different would be planning of such structures and to what extent the architect would be needed.

V. Dynamic Digital Representation of Virtual Model

The research exploring the impact of spatial structures changes on the perception, mental state and well-being of space users, applies innovative methods of virtual and mixed reality. An observer can walk through a digital representation of buildings, perceive real dimensions, surfaces, distances, and understand an architectural or urban concept in a whole new way. In the case of setting the display in stereo 3D projection, the interactive 3D stereoscopic model is provided to the participant of the presentation with the help of special stereoscopic glasses. The creation of an object-defined, structurally, financially and time specified spatial model of the building enables a dynamic presentation of the building prior to its realization. Mixed Reality (MR), which could be either Augmented Reality (AR) combining real and virtual elements, or Augmented Virtuality where the real objects are integrated to virtual scene, makes it possible to perceive the design in almost real terms, enables a virtual walk around the building with views of the surroundings, and also allows to verify variable structural and design solutions (figure 6).

Fig. 6 Verifying the construction in AR, Bentley Synchro 4D, Image courtesy of Bentley Systems.

VI. Conclusions

The research and education in the field digital tools for architectural and landscape planning design has been in place at the Faculty of Architecture STU in Bratislava since the early 1990s. The goal was to embrace this dynamic area, prepare students for practice requirements, implement innovative research ideas so as the digital technologies in the process of architectural design, verification and representation really provide progressive methods for the creation, simulation, analytical and evaluation stages of proposed structures from the viewpoint of assessing natural, technical, ecological and socio-economic impacts.

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