Digital and Architecture: Still Not a Perfect Match

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ABSTRACT

The application of digital technologies in the architectural design has long history of high promises about advances that computers will bring to the practice and relatively low inclusion of the technology in the every day practice. Today, when it is impossible to find architectural bureau without the computers it appears that digital technologies plays irreplaceable part in the architectural design. Contrary to that picture, architects rarely use digital technologies to conceive and develop their concepts. Instead they use computer applications to solve specialized problems, and often outsource professional services to perform that task. The result is that development of computer applications for architectural design is targeted toward digital professional services. Architects feel that they are loosing their profession because they can not control this level of complexity. The paper explores ways how the architects can re-establish their position it the field. The better understanding of software functionality is needed to prevent overoptimistic expectations form the software tools. The paper explores what kind of digital tools architect has at disposal and how to use them to her/his advantage. This knowledge will enable architects to establish improved communication with professional services and to obtain richer feedback that will enable better design process.

INTRODUCTION

Today it is impossible to find architectural bureau without the computers, be it small or large enterprise. All traditional paper documents that represent final outcome of architectural design process are generated using computer applications and printed using computer driven devices. Also, we read news about building information modelling (BIM) advances and technologies that enables 3D printing of whole houses. More and more examples of exceptional buildings whose design and execution were possible only thanks to computer technologies are being published in architectural journals. The presence of computers in the final phase of architectural design and positive examples from practice can create a false impression that today's practice is fully based on computers.

Contrary to that picture, architects rarely use digital technologies to conceive and develop their architectural concepts. The traditional approach to the study of the solution through sketches and drawings is still dominant. The ability to display complex geometries using drawings was developed over the centuries by the mathematicians and was accepted by the architects because it enabled the creation of increasingly complex architectural objects. Although this approach has its specific advantages in designing architecture (Evans 1986) all current innovations in the field of representation of geometry are based on computer technologies.

The big difference between drawing and the way computer applications work causes architects to outsource most tasks requiring use of computer applications to professional services. The result is that development of computer applications for architectural design is targeted toward digital professional services, making applications difficult to be apprehended by architects. In this situation architects increasingly feel that they are loosing their profession because they can not control this level of complexity.

The paper identifies the following topics as the key reasons for the fact that digital technologies still do not represent the dominant mode of work in architectural practice: modelling problem and design process problem. The better comprehension of these topics is essential for understanding functionality of current architectural design software, and is needed to prevent overoptimistic expectations form the software tools. It is necessary for architects to understand the functioning of computer technologies in order to set the correct requirements to the software developers and as a result get applications that match their expectations.

PAPER VS. DIGITAL REPRESENTATION

The beginnings of architecture as a profession at the time of the Renaissance are related to the separation of architecture from the process of construction and the use of drawings as a way to represent the architectural object. The drawing as the representation allows a designer to thought out a new building before realizing it in the real world. The specificity of designing in relation to other activities dealing with the creation of artefacts (e.g. crafts or art) is reflected in the fact that designing is limited to the creation in some medium of analogue and symbolic representations of artefacts. The significance of such an approach is reflected in the fact that our representations enable us to examine, before the action is carried out in the real world, possible alternative directions of action in one virtual world, in order to avoid the potentially dangerous consequences of our actions, or, as Karl Popper formulated nicely, allows our wrong ideas to die instead of us (Popper 1979).

For centuries, the advancement of architectural practice depended on the development of techniques for the projection of the body to a two-dimensional surface and the construction of an appropriate drawing. The first appearance of irregular curves in architecture is related to the Baroque period and is mathematically related to the emergence of an integral calculus (Giedion 1941). Throughout the history of the profession, architects used drawings on the paper as the primary way to record their ideas and to present final works.

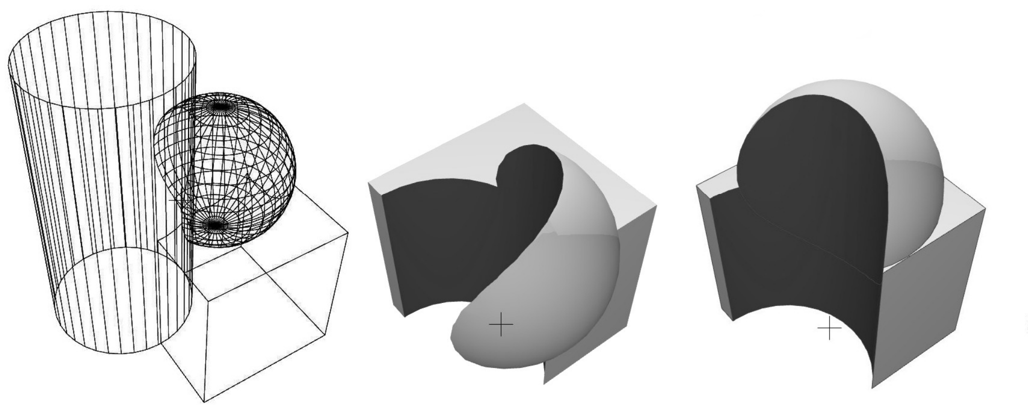
Even today, sketches on paper are dominant way of exploring design ideas (Belardi 2014). Pen traces on paper controlled by hand pressure represent dynamic medium that enables architects to explore early ideas about architectural object and still can not be replaced by any computer application. But the final products of the process are fixed drawings and writings on the paper that represent legal documents that record architect's output. This type of representation was given its credibility during time precisely because of its permanence.

The computer representations are completely different matter from the traditional static representations that architects use. The Turing machine, theoretical construct that can simulate any computer algorithm and consequently gives basic understanding how computers work, can be described as the infinite tape on which 1s or 0s are written by the read/write device that moves in both directions along the tape (Petzold 2008). The program that defines what machine is doing, data on which machine operates, and results are all written as strings of 1s and 0s on the same tape and can be all modified by the read/write device. And precisely this process of reading and modifying 1s and 0s on the tape is what computers do. Without going into a deeper understanding of the theory, this picture gives us clear understanding that computer representations are dynamic and ever changing. The similarity with the human mind is observed at the beginning of the development of computers and started an extensive debate on connection of computers and reason. In this paper, we will not go into the consideration of these questions, but we will address the question of understanding the variable and dynamic nature of computer representation by architects.

COMPUTER BASED GEOMETRY MODELS AND BIM

With the advent of computer technologies, numerous techniques have been developed for modelling geometric bodies using computers. All 3D modelling computer systems represent a physical body using a collection of points in 3D space, connected by various geometric entities such as lines, triangles, surfaces, etc. Since the definition of a geometric body point by point, line per line, and surface by surface is unacceptable from the aspect of the time spent, it was necessary to use the possibilities of computers to create procedures for generating 3D models.

It is quickly concluded that the bodies can be modelled using the geometric primitives and their combinations by using the basic Boolean operations: union, difference, and intersection. This modelling approach is known as Constructive Solid Geometry (CSG). The final model is a tree in which the nodes are 3D objects created by combining the primitives and branches are the operations performed on objects. Second important development in the computer generated geometry is based on the insight that geometries can be defined using relations between geometric bodies enabling designers to create complex 3D geometric forms using only few parameters that drive whole process. These systems enable designers to define objects using intrinsic geometric parameters (length, width, depth etc.), position, orientation, and relations among objects and to define complex geometric objects that are controlled by a small number of parameters.



Picture 1. An example of the geometric body that is modelled using the geometric primitives and basic Boolean operations. Changes in the primitive position affect the automatic generation of the geometric body.

In both cases, to obtain a representation of an object, either as an image on the screen or drawing on the paper it is necessary to interpret the model and generate second model that consists of 3D points and surfaces which is then converted into an image. The same process is required to create precise documents that are necessary for the production of 3D mock-ups, or direct link to 3D printing devices or CNC machines.

The architectural model goes beyond pure geometric information and includes information on materials, prices, ways of using space, etc. A computer model that meets all the needs must include procedures for creating geometries that are flexible enough to allow free creation and, on the other hand, to be sufficiently programmable to allow for efficient execution and to include in it all the information that gives meaning to all created elements. The search for such a model has been going on for decades (Eastman et al. 1991; Björk 1989). Today we have two technologies that are based on these researches: Building Information Modelling (BIM) and Industry Foundation Classes (IFC).

The BIM concept means to build a facility virtually using parametric three-dimensional (3D) components that have linked descriptive parameters that fully identify particular element and enable its functioning as virtual model of actual building element. All BIM applications use parametric feature based modelling combined with constructive solid geometry (CSG) to fully describe systems of complex objects. The ARCHICAD as the oldest BIM implementation appeared in 1987 and was first to proclaim the "Virtual Building" concept. The core mechanism of the ARCHICAD is based on procedural modelling language – GDL (Geometric Description Language) which is especially written for modelling architectural objects. Each element is defined as the GDL script that identifies 3D geometry, ways that 3D model maps to 2D representations, user interface display, behaviour and listing quantities. The language is flexible and enables definition of any conceivable building element and new elements can easily be defined by writing a new GDL script. The model as a whole does not have a predefined relationship between elements, so when entering new elements or modifying existing ones, it is necessary to manually correct the resulting inconsistencies. The Revit is the newer application that has in its core the parametric change management engine also specifically written for modelling architectural objects. The mechanism updates whole building model on each modification according to inter-element relationships. The elements are classified in predefined families. Each family has user selectable predefined rules that define how the element in the family relates to other elements. According to those rules each change in the element is propagated to other elements, and all related data are updated to appropriate values. A new element in the library can be created only by modifying existing families. Other applications like Vectorworks, Digital Project, or AECOsim use universal 3D modelling mechanisms and add procedures to model architectural elements so that they can functionally be included in BIM applications, but their core mechanism is not specifically developed for the purpose of architectural objects modelling.

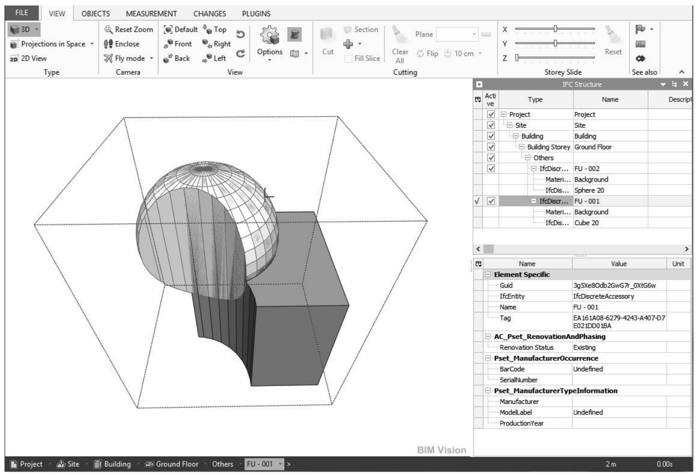
The Industry Foundation Classes (IFC) was created as a reaction to the fact that every application used in architectural design uses proprietary data formats to represent building model thus keeping all information locked in distinct software. IFC is an object oriented data model under development since 1994 with the aim to attain highest level of interoperability in AEC industry on the level of data exchange. The currently available version is IFC4 Add2 (IFC 2016). The IFC comprises of class definitions representing not only physical components of the building, but also actors and their roles, time, price, approval, etc. The standard provides data interchange without information loss among all AEC applications, unified model-based description of all building components and relationships with other components, information on the graphical representation of components, link to property and classification data, and access to external libraries. Currently, all BIM applications support import and export of their models using the IFC standard format.

DIGITAL DESIGN PROCESS

Taking into account the above mentioned improvements in the application of computer technologies in architectural design, it would be expected that it is possible to identify digital design process. Unfortunately, the differences in computer models that each application uses make the field of computer aided architectural design still fragmented.

At first sight all BIM applications share same modelling principles. The process starts with the selection of components from the library of objects, it continues by providing actual values of parameters and thus creating models of actual building components, and ends with the determination of the location of the component in the entire building model. And this is the only similarity between BIM applications. The core mechanism that the application uses fully determines the functionality of each particular BIM application. At the level of the objects library, it affects the type of parameters that define the individual object and the way in which parameters affect the object’s instantiation. Differences in the core mechanism used by each application make the elements library of each application incompatible with other applications and the architect must learn from the beginning to use the same components in different applications. The fact that each application has intrinsic process of generating architectural elements and different mechanisms of their combination to form a whole model affects the fact that often the knowledge of one BIM application is an obstacle in understanding the other.

Even though the IFC data format is designed to provide seamless transfer of information among AEC applications in reality direct mapping between BIM application’s models and IFC format does not exist. Instead, the IFC export routine in the BIM application extracts information from the native model and assigns them to the appropriate IFC data structures. In the same way, import routine of the receiving BIM applications interprets IFC file and constructs elements of its native model using information obtained from IFC file. Although the IFC is designed to support all existing computational geometry representations the differences in the core BIM mechanisms make it impossible for the computer geometry generating procedures to be directly transmitted between applications. Instead, the geometry from one BIM application is translated into a fixed geometry and then second application tries to reconstruct from that description a modelling procedure for that particular building element that is inherent for the second BIM application. In the case of standard components like walls, slabs, windows, etc. this process creates components that can be further modified in the BIM application. In the case of more complex geometries, especially custom objects and objects with free form geometry the data transfer process using the IFC format prevents the modification of objects transferred to another application.



Picture 2. The geometric body from picture 1 translated to IFC format. Relations between primitives are lost in translation and further modelling is prevented.

The BIM is conceived as a concept that connects all branches in the AEC industry and enables modelling and managing data encompassing the whole lifecycle of the building (Lee et al. 2006). The commercial BIM implementations do not reach those expectations. The core mechanisms behind ARCHICAD and Revit are designed with the aim to generate traditional documents used in architectural practice as plans, sections, elevations, schedules etc. from the central computer model of the building. With the popularization of the BIM principles, these models are expanded to include other information about objects that are not related to generating paper documents, but there is still no single view on which information must be included in the model. Therefore, for each individual connection with other applications such as energy simulation tool, structural design application, etc. a model has to be specially adjusted. In order to overcome these problems, especially in the field of energy consumption analysis, software vendors increasingly include such functionality in the applications as add-ons. But those add-ons often also require model adaptation (Jarić et al. 2015).

Many architects do not use BIM technology considering that modelling using predefined components limits their ability to express architectural intentions. They base their computer assisted architectural design process on general 3D modellers. They are often animation and rendering application like 3ds Max or Maya. If they are used only for making photorealistic displays of objects or interiors, these applications are a useful tool. In modelling architectural forms, the limitation is that they are intended to model forms that only visually resemble real objects. The underlying geometrical model that these applications use is imprecise and occasionally physically unachievable.

The second line of computer applications which is increasingly applied in architectural design is algorithmic modeller like Grasshopper and Dynamo BIM. These applications use graphical algorithm editors to represent modelling process and to enable designer to program it in a simple and understandable way. The accuracy of their models depends on the core geometric engine - Rhino and Revit. The basic problem with these applications lies in the fact that they enable the creation of complex and visually attractive geometric shapes using procedures that are purely mathematical. The fact that they are physically feasible does not mean that they are architecturally acceptable at the same time. Without understanding underlying equations and how parameters influence system's behaviour design process is striped down to uninformed selection of parameters until some interesting form emerges as the result. This process is far from the claims that architect create specific style of architecture called Parametricism

(Schumacher 2009) by using parametric geometry modelling software. In his later writing Schumacher (2012, p.619) calls Otto Frei as the precursor of Parametricism because he used inherent laws of physical processes to devise otherwise unattainable complex forms. By using algorithmic modellers just to create interesting forms architects miss the opportunity to understand dynamism that lies behind parametric geometry. By refusing to understand the dynamic model that lie behind scripts architects miss the opportunity to control design process by choosing systems of equations and selecting parameters to produce intended architectural object.

Digital fabrication is the latest in a series of innovations in computer applications for architectural design. This approach represents a radical divergence from the traditional role of architects. The possibility of direct production of physical objects based on digital models allows skipping drawings as the final product of the architect and enables a direct impact on the physical object. The process brings additional parameters into the overall design process. Limitations of materials and machines used for fabrication guide the design process. The interaction between design and fabrication process requires new architectural approach identified by researchers as the "digital chain" (Marković 2013). The direction of design process is not feedforward: from sketches, toward scripts that drives machines, and resulting in final product. Instead, a dynamic interaction between all components creates a specific system in which the interaction of geometrical, material and machine parameters creates a unique product. Formally, the final results of the process are series of commands that drive machines. Traditional architectural model loses its traditional role and becomes a link in the "digital chain" which helps to identify how machines realize design decisions.

WHAT PREVENTS FURTHER PROGRESS

Architects are still obsessed with drawings as their final products and can not understand potentials of new technology. Throughout the history of the profession, architects made sketches, plans or mock-ups as the only representation of the design process. Each of these representations is static and shows the state of the architectural project at a certain time. All the reasons for the changes and the ways in which they are implemented remain only in the architect's mind. We can say that traditional architectural representations are static time cross-sections through an otherwise dynamic process of architectural design. Today, such an approach is reinforced by the fact that the legal framework requires only static representations of architectural objects and that architects hesitate to provide any additional information that could lead them to unwanted lawsuits. Also, in the process of educating architects, it is necessary to spend a period of time in bureaus in order to get the necessary practice in direct contact with architects and through work on concrete projects.

Adhering to static representations, architects hardly accept the dynamism imposed by computer technology. When referring to the computer model of the architectural object, they only see the final product of the particular computer application and lose sight of the process that leads to it. This approach also affects the functionality of many computer applications for architectural design. When we mentioned computer based geometric models, we saw that behind them were the dynamic mechanisms that guide the entire process. Same is true for BIM models. But architects who are accustomed to traditional representations do not want to learn about the mechanisms of generation of computer models and think that this is not necessary. They usually hire firms that specialize in the use of such software and are interested only for end products – static representations of digital models.

The result of such a situation is that the dynamism of computer architectural models is not treated properly even in the computer applications. As stated earlier in the paper the difference between core mechanisms that each particular application uses prevent compatibility of models between applications. In order to enable compatibility, it is necessary to develop mechanisms for interoperability between applications. However, focusing on static representations results in the fact that even when there are technical conditions for such things, these possibilities will not be used. The IFC data format is designed to support all existing computational geometry representations and define all information that describes a building during its lifecycle, but because of lack of interest in dynamic models in the AEC industry the IFC format is used to transfer static models. This greatly complicates the use of computer aided architectural design software, since it is necessary to reconstruct the process by which the model is created for each transfer of the model into an application. In this way, the information about the way and the reasons for creating the original model is lost, and each time a new model is created that tries to reconstruct the modelling logic of old model following modelling principles of the new application.

The problem with the lack of a unified computer based architectural model also influences the collaboration between all participants in the design process. The results from the practice show that best results are obtained when all parties work on same digital model, sharing their knowledge and competence (Glymph 2003). The single, unified digital model enables coordination of information among various participants in the design and construction of a building. The principal idea is to bring together in single digital information environment different parties involved in a typical building production and to overcome differences that result from the conventional divisions of responsibility in the various professions (Kolarevic 2003). The unified digital model should be the basic driving force of the whole design process providing all participants with the necessary information. The lack of a smooth collaboration among all participants in the design also makes it impossible to create a new design process that would fit the new computer media.

The fact that architects and other participants in the building design process repeat the traditional way of working by using new technology also influence the development of computer applications for architectural design. The majority of software developers follow traditional role of representations in design process, and develops applications that facilitates creation of plans, sections, elevations, renderings, schedules, etc. They base their vision of the architectural design process on what they see in practice and create incorrect assumption that the process of design was all done through the direct manipulation of geometry. Traditional thinking of architects based on drafting conventions prevents the creation of a new design process that fully utilizes the possibilities of computer technology. Therefore, programs for the computer-aided architectural design prevents true exploratory design and does not address the new requirements to digitally communicate building model directly to all participants in the design process (Aish 2003). With the emergence of digital fabrication, this problem is becoming more and more important because the process involves machine control using a sequence of instructions that are generated based on a digital object model and completely eliminates the need for traditional drawing based models.

CONCLUSION

To make their path through complexity which new technologies impose architects need precise understanding of computer functionality. The architects should not only free themselves from seeing the architectural project as the set of drawings, they must overcome the traditional thinking based on static models. Architects must accept the challenge that computer technologies set before them and begin to think about the design process, the “modelling” part in BIM acronym. Rejecting a static view of an architectural design will allow architects to see the dynamics and programmability of the computers not as a danger and threat to their profession but as a welcome opportunity to express their architectural intentions. That way architects will re-establish their position it the field and will provide guidelines for innovations in software technology more suitable for architects. In this hype of technological innovations people forget that architects where innovation force in the field long before the computers where imagined.

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