Basic reflections on the implementation of different 3D technologies co-operating in the architectural design process

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Abstract. The constant progress of technique is inevitable nowadays and seems to be the same in a predictable future. The observation of this phenomenon leads us to formulate a few reflections on it. The use of advanced techniques causes a clearer detachment of production processes from human work. Robotics and automation were initially supposed to facilitate the production of elements, but over time they began to replace humans more and more. Will there be a place for human work in the future? It is already being pushed out of many bastions in which it was supposed to be indispensable. Autonomous cars and buses are the best example of this. Can similar phenomena be noticed in design? Will the machine replace the creator? The development of artificial intelligence (AI) shows that it is possible. Complicated algorithms are already able to compose a piece of classical music. In the case of architecture, architects are still in the lead, however, one has to take into account the conquest of this field by AI. At the moment, designers have various advanced techniques at their disposal to facilitate and accelerate their work. The most important among them are: digital 3D modeling CAD (Computer Aided Design), Building Information Modeling (BIM), visualizations, and computer animations mainly used to present ready-made ideas, but also useful at the concept stage. Apart from them, three-dimensional printing is also important, as well as three-dimensional design of structures. The above technologies are increasingly used in the design process. They are more compatible with each other than before. They allow you to save labour, accelerate the implementation of tasks, as well as to optimise the designed buildings in many respects related to construction, prefabrication or energy efficiency, to name just a few. An important, although not very common, advantage of technological innovations is their use not only during design and construction, but also during the maintenance of ready-made buildings. The best example of this is BIM, which facilitates the previous management of these technology designed objects. In the future, it will be much easier to design the adaptations of such buildings and to store information of changes which were made. This approach fits in with the idea of Management of Change, which can be included in an even broader aspect among the paradigm of sustainable development.

1. Introduction

The specific sector of robotics industry is persistently growing during last decades. The constant and rapid progress of technique is inevitable nowadays and seems to be similar in a predictable future. The observation of this phenomenon leads to define a few reflections on it. The use of advanced technologies causes a clearer detachment of production processes from human work. Robotics and automation were initially supposed to facilitate the production of elements, but over time they began to replace humans more and more. Will there be a place for human work in the future? It is already being pushed out of

many bastions in which it was supposed to be indispensable. Autonomous cars and buses are the best example of this. Can similar phenomena be noticed in design? Will the machine replace the creator? The development of artificial intelligence (AI) shows that it is possible. Complicated algorithms are already able to compose a piece of classical music. In the case of architecture, architects are still in the lead, however, one has to take into account the conquest of this field by AI.

In the next, second chapter of the paper, some aspects of computer modeling and visualization of solids are presented. Selected other three-dimensional technologies are mentioned in the next one. Using them simultaneously one by one is to some extent possible, but the most obvious seems to combine them together in a multi-stage operation. The natural consequence of the dedicated properties of individual technologies is the following sequence of their application for specific cases of the investment process. It is worth mentioning a few of them here:

a) three-dimensional modeling,
b) visualization and animation,
c) 3D structural statics analysis,
d) 3D scanning and photogrammetry,
e) additive manufacturing, incl. 3D printing,
f) prefabrication.

The fifth chapter consists of results and discussion. Some of the advantages and disadvantages of using different techniques are noted. The article ends with an application summarising the most important issues discussed in it. Conclusion has been included in the last chapter.

2. Three-dimensional modeling and visualization

Three-dimensional digital modeling has been known and used in the design and construction industry for decades. Gradually, at that time, architects moved away from drawing boards, replacing them with computer stations. Rapid progress has been made in the computing capabilities of computers from their inception to today. You don't have to be clairvoyant to predict that this trend will continue in the future. What once seemed impossible or at least unprofitable is standard today. An example may be the use of specialised software to create three-dimensional solids mapping the designed building objects. The so far dominant CAD (Computer-Aided Design) technology is gradually giving way to BIM (Building Information Modeling), which is a kind of continuation of the former, but it is better connected with parametric design.

An interesting issue related to computer modeling are file interchange formats. In the past, the primary standard for this purpose was the DWG format (originally used in AutoCAD computer program). This ensured quite good data export or import, especially over time, as the computer software dedicated to architectural and construction design became better and better. Another AutoCAD format for exporting and importing data is DXF, but it is less popular than the basic one.

All of these methods may provide enhanced use during visualization and also animation. Many programs are dedicated to this purpose, which often is an important part of the architectural design in contemporary professional conduct.

3. Other three-dimensional technologies connected to design and construction branch

Many different techniques may be used besides the afore-mentioned. One of them is the use of former prepared 3D computer model in advanced **structural statics analysis**. It can provide better optimisation of building construction during its design according to, for instance, any Eurocode that regulates it.

The photogrammetry and the 3D Scanning are other interesting techniques related to three-dimensional solids and modeling. For many years these methods were very expensive, but that situation

has rapidly changed lately thanks to such inventions like a lidar that is installed in many up-to-date mobile phones and tablets. Now, one can achieve a polygon mesh of points that is a representation of existing surrounding by quite affordable devices and save it among others also in a DWG file.

A broad list of methods called **additive manufacturing** consists among others **3D Printing**. There are many technologies in this field, for instance Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF), Stereolithography (SLA / SL), Selective Laser Sintering (SLS, or Selective Laser Sintering), Selective Laser Melting (SLS), Direct Metal Laser Sintering (DMLS), PolyJet / MJM or Color Jet Printing (CJP). In the case of professional and production solutions, which are usually incomparably more expensive than low-cost printing, the choice is also correspondingly more interesting. 3D printers working in the SLA technology (stereolithography) deserve attention, because the prints present a high level of quality, including accuracy, and the price of these devices is relatively affordable. In addition, some more advanced devices, and usually much more expensive, also allow you to get prints in many colours – from two, three, to the full range of CMYK colours. The above list does not exhaust all solutions available on the market, and besides, new ones are constantly appearing. Among the new ones, worth noticing is the invention of the CLIP technology by the Carbon3D company, which was particularly widely echoed in the world.

The above-mentioned technical possibilities are increasingly used in various fields. Examples include: science, aviation, automotive industry, art, medicine (orthopedic and dental prostheses), veterinary medicine (in particular prostheses for animals), fashion and clothing industry, toys, gadgets, jewellery, food and individual industries prepared meals or sweets (confectionery), arms industry (the possibility of uncontrolled production of weapons at home is criticised), architecture and construction. Interesting enumerations of additive manufacturing methods and applications is presented in many sources. One of them is a book of Przemysław Siemiński and Grzegorz Budzik titled “Techniki przyrostowe. Druk / Drukarki 3D” [1]. Few examples of implementation of stereolithography in the architectural design are included in my other article in “Mechanik” magazine (No. 12/2016) about this topic [2].

The rich technological and material diversity allows you to choose the right tool to achieve the intended purpose. The limited working area of the printout is often a big imperfection, which makes it necessary to fold and connect several or more partial elements with larger objects. Financial possibilities as well as the availability of the printout as a commissioned service may turn out to be a problem, especially in the case of specialist solutions.

Nowadays, you can observe the gradual displacement of people from factories due to the replacement of human work with various types of machines, such as robots, multi-axis CNC machine tools, or computers with more and more computing power and better software for specialised applications. Unfortunately, there is no place here for a broad background of what is happening in various industrial sectors when it comes to **the automation and robotics** of production and services. Examples include autonomous passenger cars, golf carts, buses, and even non-human trucks making their way through the Southwestern United States. It leads us to state a question about further automation of building process: will it be beneficial for humankind in the overall balance?

4. Results and discussions

Important benefits and disadvantages of using advanced 3D technology during architectural practice are presented in this chapter. A certain disadvantage of professional solutions such as machines or advanced software is their availability. These are often very expensive solutions. On the one hand, the high cost of acquiring these tools means that progress is made in an imbalanced way – slower in poorer regions and faster in richer countries. There are many different costs associated with this topic, especially in the field of producing tangible products. Three of them seems to be the largest: **hardware, software and**

maintenance costs. These items obviously aren't cheap many times in the case of a professional application.

The main drawback is the degree of complexity and the number of activities necessary to create a model in a given programming environment. There is also a less obvious question about, broadly speaking, **creativity**. For centuries, freehand drawing has been the basis for educating architects. This is not a coincidence. Often people who draw well in college later become great architects. Artistic skills favour the ability to create interesting architecture. During the initial stages of shaping the contours of a future building, designers still use manual techniques of imitating creative thought, especially drawing. Great examples of handmade sketches of a star architect are presented in Mario Botta's book named "Ethik des Bauens / The Ethics of Building" [3]. This is due to the knowledge gained from both their masters and their own experience, which tells them that it has a better effect. Of course, this is not an iron rule, but it is not uncommon that a unique mind-hand connection implies the creation of a work of architecture. Objects created solely with the use of computers often seem to be deprived of this difficult to grasp element that causes them to not fully achieve what architecture can be. More about the issue of sketches and drawings can be found in a book of Maria Misiągiewicz titled "On the presentation of the architectural idea" [4].

Another issue worth mentioning with the possibilities of building without human help are legal rules related to this. Actually, because of the fact that the situation in this topic may be being changed and can be completely different in many countries in the world, the problem in this paragraph is limited only to Polish law regulations. There is lack of any possibilities of special permission for such implemetation of modern technology. It means that currently a construction project cannot be created and realised without human intervention, not only for technical but also legal reasons. Precisely, in order to be able to build something, someone has to sign the project. In addition, in the vast majority of OECD countries, this can only be done by a person who is in some way authorised to do so. For example, in Poland there are independent technical functions in the construction industry, which were defined in the act – Building Law [5, article 12]. They can only be performed by people with appropriate knowledge and experience confirmed by obtaining special license called building qualifications. The latter are suitable for designing or managing construction works. Moreover, they fall into various specialties (e.g. architectural) and may be limited or unlimited. The methods of performing independent technical functions in construction include both designing and checking construction designs, as well as performing author's supervision. The involvement of a testing designer is mandatory for the vast majority of construction projects. When it comes to the implementation of investment plans, in this case, specialists are also required to perform independent technical functions in construction – construction manager, construction works manager and investor's supervision inspector. Finally, even after construction is completed, periodic inspections are mandatory for many types of buildings. Only people with appropriate permissions are predestined to perform them. All this means that, due to legal regulations, it is currently not possible to design and implement a construction project in Poland without any human intervention. Even if we assume that someone could check such a project, which was entirely created artificially by a machine, probably using AI, it would not be legal. Such a person would then act as a checking designer, but no one could subscribe to it as a designer. The computer, of course, also might not, because it cannot perform independent technical functions in construction, while it does not have the appropriate construction qualifications, apart from the fact that it is not human. This rather complex legal system is designed not only to define the roles and obligations of individual participants in the construction process, but also to outline the **responsibilities** that they bear. In particular, this applies to professional liability in construction, which has also been specified in the afore-mentioned act [5]. It is obvious that neither the computer nor the robot can bear it. The author of the software or its supplier will probably not bear it either. However, it may be incurred by people controlling the production of construction products, as it also involves the performance of independent technical functions in construction. To sum up, it is impossible to omit human work – as a designer, and in many

cases also a verifier – in architectural and construction design. However, looking at the situation in other industries and areas, one can expect a gradual pressure from the lobby of software and device manufacturers to ease the current regulations. However, it should be remembered that the broadly understood construction industry is a specific industry, especially in terms of ensuring health and life safety not only during the implementation of a construction project, but also during its subsequent use, often lasting many centuries, and in some cases even millennia.

There are plenty of benefits of combining different 3D methods, using a model originally developed for a different application. The undoubted advantage of technologically advanced devices is their relatively high reliability. Moreover, the combination of various three-dimensional methods and technologies can occur in many configurations and it can give great benefits by using a model originally developed for another application. A once prepared computer three-dimensional solid can be for instance implemented in a different technique or used as a ready-made solution. But there is often a necessity to adapt to new use. It is worth remembering that in the case of a modelled object, it is possible to use one model multiple times, e.g. for mass production, prefabrication etc. Another advantage is possibility of checking and correction of a model. Thanks to specialist applications it's easier to **find any collisions or other design errors** inside the project.

Another advantage is the possibility of relatively quick creation of **attractive presentations** of a creative idea. In addition, they can be later easily modified in order to improve the idea previously shown to the investor or on a different project topic.

Thanks to the implementation of modern three-dimensional techniques, it is possible in many cases to significantly accelerate the optimisation of a building object in relation to the specific problems posed. Thanks to computerisation, various additional analysis became more available, which were not performed due to their labour consumption, especially when they were not obligatory. For example, they may include, among others more or less automatic generations of energy efficiency, construction costs, bill of materials, list of elements, surfaces, volumes, insolation analysis, shading outline, acoustic calculations, or issues of individual industries. This can be ensured by solutions available in the serial version of specific software or, for example, by an appropriate overlay for a computer program. Advantages of implementation of 3D technologies may be noticed at individual stages of the investment process listed below:

a) planning and design,
b) realisation and production of building elements (perhaps entire buildings in the future),
c) maintenance, incl. building management.

All the above stages can be further broken down into sub-stages or separate branches, divisions, methods. However, the taxonomy presented above points to some steps that seem important. Especially the first one – creation of a digital three-dimensional model – seems to be essential. This is a necessary stage that cannot be skipped.

5. Conclusions

As you know, architecture is not only science, but also art. Can we fully automate it? You can imagine that in the near or distant future a project will be created entirely by devices – computers with appropriate applications, probably using machine and deep learning, as well as artificial intelligence. Will it then be a work of art or just a product of technology? Theorists will argue about this.

The boundaries of art in the twentieth century have been greatly expanded, including thanks to Marcel Duchamp provoking the world public opinion with his works and thoughts. One cannot forget about his successors, who continue to free the understanding of what is art from the usual patterns. An open question remains whether and when technological revolutionaries will attempt to create a building

without human intervention? Other barriers to this goal are gradually being removed. It happens partly involuntarily, and the largest share of it is the private sector, in particular global and local corporations that usually deal with only a certain part of the market, e.g. computer software for construction industry specialists. The small steps of individual units scattered around the world are gradually becoming more and more intertwined and make such futuristic visions as the idea of designing and building without human intervention more and more real, perhaps in the not too distant future. This is in line with a global trend. More and more technological innovations are being implemented in new industries. They are mainly aimed at facilitating and automating production and services, limiting human work by replacing it with robots, machines, computers, or other devices. The scale of this process in the world varies. The leading countries in this field are, of course, the most economically developed and industrialised countries. It is a new revolution, or at least the next stage of the industrial revolution that has been started over two centuries ago, which completely changed the ways of producing goods and, by the way, entire societies, and entailed unimaginable changes in almost every area of life.

Thanks to the implementation of modern 3D techniques, it is possible in many cases to significantly accelerate the optimisation of a building object in relation to the specific problems posed in the article. This can be ensured by solutions available in the serial version of specific software or, for example, by an appropriate program overlay. The best example of this is BIM, which facilitates the management of previously designed in this standard objects. In the future, it will be much easier to design the adaptations of such buildings and to store information of changes which were made. This approach fits in with the global trend of digitalisation of building process and the idea of management of change, which can be included in an even broader aspect among the paradigm of sustainable development.

It is definitely not the time yet when a sketchbook should be replaced by a computer application. Similarly, in the field of design, man still wins over the machine, which is not so obvious in many other areas.

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