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BIM FOR COST PERFORMANCE OPTIMISATION OF CONSTRUCTION PROCESSES

Keywords: BIM, project, construction, productivity

Abstract

Our world is changing faster than ever before. Urban areas all over the world have been developed rapidly. Unfortunately construction sector has been rejecting most of the technological opportunities while other industries have undergone significant changes over the last years due to some process and product innovations. The sector has still an intractable productivity problem. However, construction is the world’s largest industry in terms of resource (including energy) usage and waste generation. Improving whole-life cycle resource efficiency and environmental impacts are considered the main challenges of the construction industry in the European Union. Such improvement can be reached thanks to digitalization, advancement of computational tools, brand new construction techniques and methods as well as innovative technologies. Incidentally, companies can boost productivity as well. To make cost performance more efficient, planners/designers should explore more construction/design alternatives and - as a result - make more accurate decisions. High complexity of the construction projects reduces a simplicity of setting up a reliable construction model ready to multi-objective optimisation. Building Information Modelling (BIM) is considered as the innovation that allows for the consistent management of information in the construction projects. This tool turns out to be useful in managing the process of building construction in the whole-life cycle perspective. Additionally, people, standards, processes and the technology form the integral parts of BIM. It is inevitable that construction companies would customise BIM gradually and have to refine and attune the method with increasing know-how.
Introduction

The construction industry has a significant impact on the global economy as well as the environment. According to some recent reports, it accounts for 6% of global GDP, it is also the largest global consumer of raw materials, and its outcomes (building and other structures) account for 25-40% of the world’s total carbon emissions [1]. Meanwhile, the sector has the greatest potential for carbon reduction with the lowest cost [2]. The European construction sector output of €1.3tn is approximately 9% of the region’s GDP and it employs over 18 million people [3].

Building Information Modelling (BIM) is a very broad term which describes the process of creating a digital model of a building, road or other structure that contains different kind of information. Moreover, it contains information about the components, and their properties such as function, shape, material, cost and processes of the building lifecycle [4].

Fig. 1. Malta House, Poznań (Poland) – considered as the first building in Poland designed and completed in BIM technology exclusively

Source: [5].

For the purpose of this article, which is about a concept of the whole life-cycle cost optimisation modelling, Building Information Modelling was defined as a technology to create a model that contains information [4] used to achieve benefits throughout a project lifecycle [6]. In addition, the European Commission’s EU BIM Task Group maintains that BIM is a
strategic enabler for improving decision making for both buildings and public infrastructure assets across the whole lifecycle [3].

**Intractable productivity problem**

According to some market research, the construction sector has been rather resistant to adopt and adapt to new technologies than other globally significant sectors. While some innovations were implemented on the enterprise or company level, still overall productivity in the sector has remained nearly flat for the last 50 years [1].

On the basis of the Eurostat data for construction of buildings, it was calculated a quantitative relation between the production value of the construction sector in millions of euro and the number of employees in this branch of economy in five different countries: Bulgaria, Germany, Spain, Poland and the United Kingdom (Figure 2). It is interesting that few countries show a significant change, whereas the UK presents an unusual raise in the ratio after 2011, what may be conditioned by BIM implementation and other investments in new technologies in this country.

Fig. 2. Labour productivity ratio in chosen countries

Source: own elaboration.

Moreover, construction projects are becoming ever more and more complex. Cost and time pressures are rising, whereas quality expectations are increasing in the same time. In response, this sector has to find a way to reduce complexity and costs, raise productivity and assure quality [7].
Especially in megaprojects, there are many repetitive and non-repetitive processes that based on traditional design and construction make the project quite complex and complicated to manage. In fact, an implementation of BIM can reduce a number of misunderstandings connected with a construction phase by putting all the data and the changes into one digital model which can be available for all project stakeholders. It has a significant impact on the duration of the project and the productivity as well.

An access to inadequate information during a construction phase has been consistently identified as a factor that contributes to poor productivity and rework. This in turn contributes to schedule and cost overruns, and disputes between project stakeholders [8].

According to [9] it has been revealed that BIM is an innovation with a great potential to positively impact labour productivity in the construction industry. It gives more efficient design or better access to relevant information for managers. Moreover it creates favourable conditions because of fewer conflicts and better quality.

Today buildings are in some way ‘digital’ in terms of the users’ IT requirements and because they have systems used to monitor and control the areas of facility management. Such inbuilt digitisation of the modern structures should be utilised to create an immediate productivity by BIM adoption [4].

There are many examples that construction companies invest in BIM i.a. to boost their productivity in the construction process [10]–[13] and they understand the importance of these innovative solutions.

**New approaches to building planning**

For some years, a digitalisation of the design and construction processes has been considered as a cure for low productivity in the building sector. According to [14], these processes can best be viewed as an integrated system. In fact, a construction investment project is a system of complex tasks assigned to different subjects, with specific start and finish dates, a budget, a plan, and intended to deliver a product of the construction activity as a project result [15]. In such system, different sections (e.g. procurement, logistics, design, construction) can undergo the process of changing to digital era. The transition is present i.a. among producers of building materials. They focus more on “digitizing production and distribution (along the lines of Industry 4.0 and the design of the customer journey)” [7]. On the other hand, contractors concentrate
primarily on the digitization of planning, construction and logistics. For their part, building material traders strongly influence on their logistical considerations with digital sales strategies.

It seems that a standard design process with 2D plans and vast printed documentation becomes quite old fashioned nowadays. Even though it has a low credibility and exposure to design errors, it is still used in majority of the construction projects. However, a new technology (BIM) is getting more and more popular among those stakeholders who are interested in increasing reliability of the design process. It is conceptualized to be a technology which enables the digital simulation of a construction (structure prototyping) before its physical occurrence. It enables for sharing information to all project stakeholders across a project's lifecycle. It has to be noticed that according to recent studies, nowadays BIM is most often used in the design and pre-construction stages, with notably lesser use in other periods of the project [16]. In order to make more profit from this attitude, managers have to realise its usability in whole-life cycle.

As stated in [9], the adoption and implementation of BIM in the construction industry is stimulated by the promise of increased labour productivity. Indeed, a brand new approach to project delivery appears as a solution to break recent trends and move the labour productivity in the construction industry from an apparent stagnation or even decline.

Apparently, BIM creates new lines in building planning. BIM-based models can be treated as a basis of game scenarios that can be quickly implemented. Its most important strength is that construction project planners can simulate various scenarios very quickly [17]. It has to be underlined that the building sector does not recognize a full potential of BIM. In fact, a key advantage of this method is that a digital simulation of the project is possible before any production task is taken on. Therefore, BIM minimises planning errors, permits fast calculations, quantifies extra costs and shows alternatives [7].

Intentions connected with a successful implementation of the development force on planners to be able to make informed decisions. The directions chosen in the early planning stages have significant influences on the project. To decrease uncertainty, planners have to formulate multiple development scenarios mainly of different designs and/or development schedules. It has to be remembered that more alternatives give more opportunities to make better decisions. According to [18], there is a key direction to minimise project risk and to optimise decisions: planners could enhance the collaboration among stakeholders if
they could assist the stakeholders in clearly understanding the alternatives. It would be significant if they could verify the impacts of each alternative on comprehensive sustainability and the resources required at different points in time during the construction and operation phases. Such attitude is possible thanks to BIM software which enables for project simulation (Figure 3).

Fig. 3. Example of BIM software interface enabling project simulation

Source: [19].

All in all, the Building Information Modelling can be compared to military simulations in the army. Because military systems appreciate advantages of the simulations, BIM is likely used there too. For example, the U.S. Army was one of the original pioneers of the technology [20], [21], having published the Army “BIM Road Map” in October of 2006 [22]. In a certain sense, BIM can be treated as a kind of training system with a specific application in the construction sector.
BIM useful for companies

Construction projects are executed by different stakeholders. Among them, there are construction companies of all sizes involved in a construction phase usually as general contractors or subcontractors. The size of contractor is tailored by the size and complexity of the construction project. The more complicated a project is the more resources (capital, human, equipment etc.) it requires. According to Eurostat database [23], in 2014 in the European Union there were 3,240,959 microenterprises (from 0 to 9 persons employed) and only around 1,900 large companies (250 persons employed or more) out of total 3,441,304 (94.2%) operating in the construction sector. It seem quite obvious that excluding micro, small and medium enterprises (SMEs) from a discussion about BIM is wrong and bring them to the margin of competitive space. According to [24], the majority of the organisations that have adopted BIM in project delivery in the UK construction industry were large organisations that are more likely to be prepared for adopting BIM. Small and medium enterprises, although less keen believers in BIM, are nevertheless very important players too. Assuming that BIM implementation results in considerable financial risk, especially for SMEs, clear benefits must occur and be countable in order to encourage them to continue the BIM-based strategy. One such advantage that is stimulating the adoption and implementation of BIM in the construction industry is the promise of increased labour productivity. This new approach to project delivery in construction industry is considered as a solution to change the evident stagnation and even decline of labour productivity [9].

Global market show different levels of advancement in implementing BIM. According to McGraw Hill, the United States, the United Kingdom and Canada became the world leaders in BIM implementation. On the other hand, there are many new adopters of this technology in such countries like France, Germany, Brazil, Japan, South Korea and Australia [25]. In the European Union, some recent efforts of the EUBIM Task Group open space for harmonising a European wide common strategic approach for the introduction of BIM [3]. According to [26], “for public works contracts and design contests, EU Member States may require the use of specific electronic tools, such as of building information electronic modelling tools”. It means that the European Union authorities seriously think about new digital area of the construction sector. Moreover, Member States should have brought into force “the laws, regulations and
administrative provisions necessary Directive by 18 April 2016”. However
the application of these regulations until
In front of such transition, it professionals are on the eve of re-ad
shift of BIM in practice of the but proposed to follow some steps (Figure
BIM implementation. Starting from
market standards, legal regulations and

Fig. 4. Three tiered roadmap for BIM i

Source: own elaboration.

Each stakeholder has to inculcate starting from the pro-innovation culture
highly modified BIM-based processes (reengineering) and investing in proper
(compare Figure 5). After years of
BIM-based decisions, the stakehold
achieve satisfactory results in using I
maturity. The most detailed level – pt
of BIM advantages among all stakehol
Fig. 5. Hierarchy of the key success factors of BIM implementation in an enterprise

Source: own elaboration.

Figure 6 represents BIM manager’s areas of interest. It is proposed to treat him as a stakeholder which is involved in every step of the construction project: design, quantity take-off, cost estimation, schedule, construction, maintenance and liquidation. Moreover, BIM manager needs to coordinate four aspects of the construction project: people, technology, policy and processes.

Fig. 6. Particular steps of construction project (on left) and BIM manager’s areas of interest (on right)

Source: own elaboration.
A standardisation of processes in construction projects and improvements in the flow of information thanks to a common digital model, saving up-to-date information, show crucial advantages of BIM.

Fig. 7. Map of factors present in optimisation procedure; upper part represents BIM-based approach to optimisation, lower part represents areas of seeking the optimal level with an influence on a construction project.

Source: own elaboration.

Figure 7 shows the factors that may be present in optimisation procedure. There are usually four areas [27] of seeking the optimal level in the project: time, cost, scope and quality. Whereas the construction project can be analysed from point of view of the construction company, construction process, resources used in the project and its logistics. It is crucial that overall optimality in the project resulting in the lowest project risk has to be determined by assuring the optimality of each element.
mentioned above. Among a variety of the factors influencing the project success, the *trust* deserves special attention. This social aspect of the project is difficult to quantify. However, it is very crucial and connected with a phenomenon of *fairness* in the construction project. It has to be underlined that this particular problem appears in the literature more and more often.

**BIM-based optimisation model**

According to Project Management Institute’s standards lifecycle costing as well as value engineering techniques along with constructability analysis are used in construction projects to “reduce cost and time, improve quality and performance, and optimize the decision-making” [27]. In fact, difficult decisions appear in every phase of the construction project. However, the most crucial step of such projects is an early stage [28] when the level of sustainability, performance, and life cycle cost over the project can be influenced the most. Therefore multidisciplinary optimization for high performance building design can provide desired performance feedback for decision making during the design process. It may also support designers in choosing the best design alternatives after the assessment of their impacts on the performance. Optimization is a reliable method to achieve high performance building design, but it is nevertheless used quite rarely in the practice due to its complexity. According to [2], it comes from “the large number of multidisciplinary interrelated parameters involved in optimizing building performance as well as the complex natures of building simulation outputs”. Because of this, there is a great demand of utilizing and integrating the advanced modelling and simulation technologies. One of such solutions is BIM, parametric modelling, cloud-based simulation, and optimization algorithms.

In order to make accurate, optimal and low-risk decisions about construction projects, the building performance simulations are recommended. Such procedures are possible owing to the fact that BIM delivers relevant building information which is required for building (cost, energy, sustainability) performance analysis. It reduces time in preparing input data for building performance simulation and makes the outputs more reliable. The literature review revealed that “though parametric BIM-based performance optimization could significantly benefit high performance building design, there are only a very limited number of research studies on creating an integrated methodological
framework for BIM-based multidisciplinary performance optimization” [2].

It is proposed to execute an optimisation procedure of the construction project which is based on three steps: project modelling, data collection, simulations and improvements. In the article, it is described a cost performance optimisation procedure. Figure 8 presents a conceptual model of construction project for cost optimising procedure.

STEP 1 – MODELLING A CONSTRUCTION PROJECT

Fig. 8. Model of construction project for optimising procedure

Source: own elaboration.

The cost optimisation in whole life-cycle begins with a creation of the construction project model. It represents four phases of a typical undertaking: design, construction, maintenance, liquidation (Step 1). It is crucial to prepare for each phase two types of data: deterministic values of the cost and probabilistic values (PCD𝑖) based on historic data or alternatively they may rely on predictions of the panel of experts. Then a calculation of the deterministic (Equation 1) and probabilistic (Equation 2) life-cycle costs is performed (Step 2).

STEP 2 – COLLECTING NECESSARY DATA AND PERFORMING AN ANALYSIS

\[
\text{DETERMINISTIC COST} = \text{sum} (DCD_i; DCC_i; DCM_i; DCL_i)
\]  

(1)

where:
DCD𝑖 – deterministic cost in ‘design’ phase
DCC𝑖 – deterministic cost in ‘construction’ phase
DCM𝑖 – deterministic cost in ‘maintenance’ phase
DCL𝑖 – deterministic cost in ‘liquidation’ phase
\[ PROBABILISTIC\ COST = \text{sim. random}(PCD_i + PCC_i + PCM_i + PCL_i) \]

where:
PCD_i – probabilistic cost in ‘design’ phase
PCC_i – probabilistic cost in ‘construction’ phase
PCM_i – probabilistic cost in ‘maintenance’ phase
PCL_i – probabilistic cost in ‘liquidation’ phase

A complexity of the construction-investment projects results in a risk of achieving some established goals. In this case, risk can be defined as a probability of lack of the success of taken actions [29], [30]. Cost risk (Equation 3) is calculated as a relation of the absolute value of subtraction of the probabilistic and deterministic cost to the deterministic cost.

\[ COST\ RISK = \frac{|PROBABILISTIC\ COST - DETERMINISTIC\ COST|}{DETERMINISTIC\ COST} \cdot 100\% \]

A third stage of the cost optimisation concerns improvements of processes in order to find an optimal cost (Equation 4) under given criterion. The criteria are usually representing best alternatives for expected quality standard, best alternatives for budget, lowest cost risk etc.

**STEP 3 – SIMULATION-BASED IMPROVEMENTS OF PROCESSES**

\[ OPTIMAL\ COST = \text{optimality.criterion}(COST\ RISK) \]

Simulations finish when the minimum cost, in established boundary conditions, is reached. Future works will start from collecting data necessary for simulations and creating software collaborating with a common BIM software to conduct the cost optimisation analysis.

**Summary**

Lately, some governments have adopted strategies to increase a role of BIM in the industry. The industry, on the other hand, is to be responsible for adoption and utilization of BIM by providing information, training, standardization, development, and of course infrastructure [5]. Nowadays BIM is most often used in the design and pre-construction stages but it has to be underlined that a great potential of BIM is associated with the operation and facility management.
Currently the industry in many countries is attempting to adopt BIM as the future standard for construction projects. However, the adoption rates have been lower than expected. According to [31], various barriers impeding implementation have been identified. It is important to note there is not a single barrier that is completely responsible for hampering BIM adoption. In many countries, public authorities are committing to the new technology by requiring it in all new public projects. If project stakeholders understand the benefits of BIM, they will aim to implement it from the earliest phases of the project.

The article explained benefits of BIM implementation in the organisation. Moreover, it described three stages of the cost optimisation in the construction projects. Future research covers data collection and software as an add-on to the BIM software to conduct the cost optimisation analysis.

REFERENCES


