Optimization tools and BIM: A marriage with a future?

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Abstract

The use of optimization techniques with Building Information Modelling tools is not widespread. The digital approach of Building Information Management (BIM) has several possibilities in construction that have not yet been explored. This paper aims to describe the possibilities of combining meta-heuristic optimization techniques, proposing possible synergies with benefits for the quality of construction and design. BIM can perform as a database of relevant construction information, and the optimization techniques can automatically analyze the choices from the data available related to possible choices. The combination can lead to optimal design and construction.

Furthermore, this paper will discuss the use of machine learning and cloud computing tools. Moreover, considerations are proposed concerning the respective possible benefits. Finally, a description of three possible scenarios illustrating processes and possible benefits are presented.

1. Introduction

Evaluating the design's efficiency is considered a real challenge for Engineers. Newly developed optimization algorithms embrace effective techniques to optimize the building design. Some of these are meta-heuristic approaches such as artificial bee colony, particle swarm optimization algorithm, moth-flame optimization, ant lion optimizer and whale optimization algorithm [1]. The algorithm's performances are evaluated quantitatively and qualitatively using convergence speed, solution quality and robustness. The design optimization problems involve multiple objectives and mixed variables, with nonlinear constraints showing performance, geometric conditions and material choices. Several mathematical programming algorithms have been developed during the last three decades to solve various engineering and industrial applications problems [2]. Generally, most of these methods always require the knowledge of the gradients of the objective functions and constraints. In most cases, the classical algorithms can find globally optimal solutions while terminating when the function's gradient is very close to zero, and this can happen both in the case of local and global solutions [3].

BIM is the acronym that started as Building Information Model, then Modelling and currently Management. It represents construction works in several stages and forms. It has many applications in construction and other industrial designs. Digital Twins is a recent approach where a digital representation is created to replicate and simulate the building or construction works. Initially, BIM was a 3-dimensional representation of a construction or a mechanical piece. Currently, other dimensions have been added to the use of these programs. It is used in various aspects such as quantity surveying, design clash conflicts, planning and scheduling, safety, architectural design, structural analysis, comfort (acoustic and thermal) evaluation, among others [4]. These software programs are generally used to visualize operations and verify compliance with regulations, norms, owner objectives, costs, and intended outcomes. Of course, it has been a successful approach to store and manage information in construction, especially buildings information. It has become very relevant for information management in a structured mode to benefit the participation of stakeholders like engineers, technicians, architects, designers, technical directors, regulators, and educators. The main reason is to improve the quality of information managed with BIM tools and facilitate access to the data in an organized manner.

Buildings and constructions are becoming more complex, thus, making it difficult to manage and operate information effectively to make proper decisions. Decision-making and optimization tools have not been commonly used with BIM tools. This text intends to summarise the analysis of three case studies where the use of BIM has been complemented with the interaction with proper optimization tools like the meta-heuristic [5]. The three case studies represent the use of BIM to promote construction safety, BIM to control the costs and performance of a wall, and BIM to verify and illustrate the use of structural design. In these three analyses, some optimization methods and digital tools may be linked to the decision process, and consequences are evaluated for efficiency and effectiveness.

2. Optimization methods

Solving optimization problems in building construction is a challenge to choose efficient algorithms. Usual optimization algorithms are based on the system's responses and the sensitivity analysis in terms of the optimization function and related behavioural constraints. These optimization techniques are based on the effective use of gradients of the numeric expressions that characterize the system. These gradients are calculated numerically or explicitly depending on the definitions of the systems. Problems usually addressed can be planning schedules, choice of materials, design of structures and other systems, the topology of elements or systems, costs or profit improvement, and performance.

The use of gradients and Hessian-based optimization methods has been outpaced recently by other techniques based on neural networks, network theory, sequential quadratic programming, and interior-point methods. In the last decades, algorithms have been produced using meta-heuristic methods. Some of these are particle swarm optimization (PSO) algorithm, ant lion optimizer (ALO), grey wolf optimizer (GWO) and mine blast algorithm (MBA) [1].

These algorithms are generally compared in terms of the solution's quality, speed of convergence, and algorithm robustness when addressing optimization problems that are considered adequate for evaluating the different approaches. Most engineering problems have solutions using established techniques and methods. However, the optimization approach is at a higher level of proficiency while providing better solutions in terms of the optimization criteria than the majority of the acceptable solutions. These considerations also apply to building construction, designs and executions. Options made during the design and the execution influence the optimality of the choices, and the optimization techniques can be used to improve the decision-making process. Some difficulties in finding optimal decisions are related to several economic, scheduling, and technical constraints.

Generally, optimization problems have multiple objective functions and variables of different nature. Functions and constraints are nonlinear, and variables may be discrete or continuous sets. Classical algorithms find local optimal solutions based on gradients instead of the global optimum. Since deterministic approaches are not based on gradient techniques, they have been replaced by metaheuristic methods to find optimal solutions. These non-gradient-based methods may be classified into three categories: swarm-based, physical techniques and evolutionary algorithms. In short, swarm-based techniques are based on the collective behaviour of a given population of solutions. The evolutionary algorithms mimic the Darwin theory, where the latter solution has evolved optimally from the former. The physical techniques are based on simulations of solutions using a Monte Carlo method.

For example, the swarm-based technique is Particle Swarm Optimization (PSO), based on a mathematical representation of animals or social behaviours such as birds or fish. The principle is that it starts with a random choice of entities of that group. The second step is calculating the robustness indicators (position and velocity) of each particle (animal), the third phase consists in recalculating the global and individual optimal values, and the fourth step improves the related indicators (velocity and position) of particles. The steps are repeated until the criteria of stopping the search is obtained [6].

A well-known type of evolutionary algorithm is the group of Genetic Algorithms, a search algorithm based on the mechanics and procedures of the natural selection process based on Darwin principles. The optimal solution is obtained by the survival of the fittest that suffer evolutions identical to the crossing and creation of genes (solutions). Some optimization techniques have been derived from differential evolution, evolution strategy and biogeography-based optimizer [7].

The third group of meta-heuristic optimization methods is based on physical processes, primarily using Monte Carlo and Simulated Annealing techniques. Recent ones are gravitational search, central force optimization, small world optimization and charged system search. This group has tested and applied methods in several areas of industry. The Simulated Annealing algorithm is based upon heating material until it reaches an annealing temperature. Then it will be cooled down slowly in order to change the material to the desired structure where the optimal solution is sought [8].

The description of these possibilities of meta-heuristic optimization techniques suggests that these approaches can handle the difficulty of representing the optimal criteria in building construction and designs in numerical functions like economic or performance characteristics. Some definitions of criteria for choices, like life-cycle costs or like thermal and acoustic performances, may be hard or impossible to define by an exact or approximate numerical function. It is known that meta-heuristic algorithms require internal control parameters like starting points and penalty functions. Properly handling the inequality and equality constraints may be crucial to obtain optimal solutions but can be handled together with other criteria to obtain the optimal solution.

3. Building Information Management

Information in any construction process is crucial in all the project life cycle. Information generates all procedures and phases of construction such as design, bill of quantities, drawings, technical specifications, bidding, contracts, legal compliance documents, health and safety plan, execution, changes in design, maintenance plans, and built elements. The construction process is composed of operations aimed at handling information. Generally, the supporting documents for the construction have been produced and used in digital formats. The use of digital documents has facilitated document management of information. On the other hand, the possibility of using digital documents and supporting digital platforms using internet portals has increased the manipulation of information related to each construction project [4].

BIM is an example of how to treat information related to construction digitally. It has been recognized mainly for visually representing the intended construction. However, the most significant advantage for efficiency and effectiveness in the process is placing all possibly relevant data in one place. In the last three decades, building information was organized in dimensions, starting from 3D, representing geometric building information. Other information costs, planning, sustainability, sequence of operations, physical characteristics and other properties have been classified as 4D, 5D, among others.

Furthermore, a recent standardized categorization came into practice defining the Level of Information Need of the BIM models [9]. In general, the Level of Information Need describes the granularity of information exchanged in terms of geometrical, alphanumerical, and documentation. The primary purpose is to define the level of information needed to prevent the delivery of too much or unnecessary information. The Level of Information Need describes information requirements that can be human and machine-interpretable. Thus, it can deliver clear benefits to all participants in the various project life cycle since the standard provides a common understanding of the right level of information needed at a specific time. This categorization has been developed because several conflicting terms, concepts, and usages in place, both internationally and across Europe, hinder having a shared understanding and practice in describing the level of information need for a common European market.

Due to this possible use of information aggregator, BIM could mean Building Information Management. If that assumption is pursued further, it is natural that management decisions with the Building related data should be supported by optimization methods when decisions are necessary every time options are available. Design and construction objectives are compatible with typical optimization approaches to obtain better results. BIM, as it exists, can perform as a database about the Building where solutions at every level can be evaluated using criteria typical of any design or construction.

Another digital supports to make the right decisions when using the optimization techniques can be complemented by cloud computing, where data related to materials and designs can be stored, and the use of machine learning while complying with legal and performance requirements. Cloud computing is available in construction and has had many applications in various services like databases, networking, software, and data analytics. Creating initial solutions in the meta-heuristic optimization techniques can be an excellent approach. As a branch of Artificial Intelligence, machine learning is used in construction and, for instance, can help the improvement of safety compliance. It can help assess risk situations based on data analytics and prediction rules. A definition of machine learning is the capacity of defining rules for decision making based on the analysis of existing data. These two applications can combine access to an extensive data bank (Cloud computing) and decision rules when facing options (Machine learning). In recent years, automation and digitalization enabled higher performance and accuracy in the construction and design sectors, hence, reducing costs and modernizing production.

4. Possible synergies between BIM and optimization techniques

After considering the possibilities of the optimization techniques and BIM characteristics, it is possible to envisage synergies that can lead to better design and construction. At least it increases the possibility that this synergy may produce a result better than the one produced using this "marriage". The availability of Application Programming Interfaces (APIs) for popular BIM authoring tools and Visual Programming Languages (VPLs) have opened new possibilities for construction specialists who can develop sophisticated analysis tools in different domains without requiring steep learning curves. Three examples are presented that may illustrate the scenarios for successful cooperation. These examples are just a small sample of the possibilities that the combination of optimization techniques and BIM may benefit the quality of construction.

In terms of accident prevention management and using available information on accidents in construction may lead to an analysis of the most appropriate prevention measures. As mentioned, risk prevention can be identified using cloud computing for similar situations in buildings and the machine learning capacities to identify the possible prevention measures. Indeed, available records can help identify tasks (use of formworks) and scenarios (slab openings). After preventive measures are identified, the optimization techniques can search for more effective and less costly. The optimal set of preventive measures can be adopted to have the right combination of effectiveness and cost. It is important to highlight that it is necessary to find an optimal compromise between the preventive measures and safety since human resources and materials are limited. It is impossible to prevent all accidents, and it is an unsustainable approach. Better prevention management can be obtained with the use of proper digital tools. Information about the chosen preventive measures can be added to the building data and presented to the stakeholders. One of the first studies that provided a framework for safety in BIM was by Zhang et al. (2011, 2013). The study proposed a safety rule-checking system that applies fall protection such as guardrails and covers automatically to a building information model [10].

A second example is the possibility of choosing the suitable materials that are optimal for the combination of thermal and acoustic requirements. Cloud computing can provide information about the physical properties of materials and techniques available for the execution of the wall. Similarly, the data related can be obtained for the several options. The optimization techniques would then use the chosen function that combines the designer, or the construction manager, valuation of the physical characteristics of the options and the importance of respective economic implications. The optimization models can then proceed to search solution(s) that satisfy the constraints and the optimization function or criteria using those criteria and the legal and performance requirements. Similarly, stakeholders can observe the first case options in the three-dimensional representation with dimensions and display changes.

The third case of possible benefits of suggested optimization techniques is related to the supporting structure's geometry or topology. This approach can lead to optimized structural solutions based on a reference configuration or original performance-based geometrical configurations. Options for configuration, dimensions and types of elements can be considered. In terms of configurations, the length between vertical supports (columns) can be variables, related dimensions (width, height) of elements can be variables, and the materials of elements can also change (reinforced concrete or steel). Using an appropriate function that reflects the valuation criteria (cost) of the variables, inserting constraints in terms of codes and stability, the optimization techniques can be employed to find an optimal solution that can satisfy the structure's functionality. The structural properties and information can be inserted into the model. Thus, the related effects in terms of the topology of the structure, geometrical implications, and interactions with other aspects in the virtual model can be observed and analyzed.

These examples illustrate a few possibilities that can be explored by integrating stakeholders' tools and sectors, leading to more efficient and effective procedures for better designs and constructions, leading to a sustainable future for the built environment. For instance, sustainability concepts can be used as optimization criteria or constraints to ensure adequate BIM according to concerns related to the life-cycle analysis of materials and constructions.

5. Conclusions

As BIM authoring tools become more customizable, the possibilities of developing performance-based designs using BIM data and optimization tools have increased significantly. APIs and VPLs that enable users to develop addons without necessarily requiring formal programming skills have changed how BIM tools can be used and are now increasingly common solutions for tasks throughout the construction life-cycle.

Although the technological solutions that enable a fruitful relationship between optimization methods and BIM are well-known, construction specialists are often not aware of the possibilities that arise from this. Indeed, further effort in educating and training construction professionals is required to reap the benefits of combining information-rich building models with data-hungry algorithms.

Evolution of meta-heuristics optimization algorithms linked with the interoperability of BIM tools suggest that more case studies and applications of joint applications will be available in the near future. Use of cloud storage, data mining, applications, artificial intelligence and sustainability requirements will foster the synergy among existing tools and will be available for current designs. The possibility of obtaining quickly, reliable, better designs will lead to a more consistent use of available construction resources.

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