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Research paper

Automation in Civil Engineering Design in Assessing Building Energy Efficiency

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Abstract

Automation in Civil Engineering design is no longer unfamiliar anymore in the construction industry. It brings great efficiency gains and has reduced many of the complicated aspects of design. Automation has been developing since over the last four decades where advancement of computer hardware and in line with software developments has enabled various sort of design to be computerized. The design process is now more fast and accurate, and the entire process has been outstandingly improved by the available technology. However, the problems related to computerized design, started from the possibilities for unrecognized or unanticipated consequences as the design becomes more complicated. In line with it is the global warming issue that has been threatening the human being. Therefore, this paper reviews the design automation and its application in civil engineering design emphasizing in assessing the energy efficiency of buildings, which includes background information, its application, advantages, and challenges and also suggestions to further improve the automation in civil engineering design by artificial intelligence (AI). It was discovered that since over the past few years, BIM implementation in Civil Engineering design has started to be adopted massively in construction industry due to its tremendous advantages. In this paper, a new flow process in design automation in assessing building sustainability has been proposed by implementing AI BIM which is linked with MyCREST, a green rating tool in Malaysia in order to assist designers to conceptually design for a more energy efficient building.

Keywords: *Automation; Artificial intelligence; Building Information Modelling; Civil engineering design; Energy efficiency*

1. Introduction

Over the last four decades ever, more advanced computer hardware and corresponding enhancements in software have allowed tremendous sort of design to be computerized [1]. As the construction industry enhances its digital journey, the automation in a design application is developing, making the process of development becomes more organized and less-time consuming [2]. As stated by Farinha *et al.* [3], since the beginning, structural design process has been accompanying the ICT revolution. However, there are several vital areas in which the procedures are totally dependent on the engineers were considered, until lately, to be complicated and even not possible to be programmed. This is especially so since they are not only of a numerical nature but are also acquire heuristic knowledge. Such issues can now be solved with the assistance of diverse updated ICT applications [3]. However, the initial design stage in Architecture and Construction projects which is a crucial part of the sophisticated long-term design process is still less automated and more human depended on part of a complex design process [4]. In addition, aligned with the ICT revolution and global climate change, owners, architects and engineers to date are more concerned on detailed digital representation in order to incorporate a broader range of aspects for instance the life-cycle of buildings, sustainability and energy performance of proposed buildings. It also will be needed to assist to enhance accuracy and productivity in construction and will be an important feature of the future automation in the entire construction stages [5, 6]. This is where the further automation of the design process is currently evolving in line with the recent demands.

"Automation is the technique, method, or system of operating or controlling a process by highly automatic means, as by electronic devices, use of control systems and information technologies, reducing human intervention to a minimum." Vähä *et al.* [7] have also agreed that automation is the implementation of information technologies and control systems to decrease the demand of human effort in producing goods and services [7]. It also has been stated that automation is an important advancement to guarantee successfulness of evolution of CAD. The computation power of IT should allow the computer to execute the calculations and produce results for the users to review and finalize [8].

There are tremendous advantages of the application of automation in civil engineering design. Automation as a whole will assist the design process to be faster, more accurate, and play an important role in the reduction of error. One of the traditional sources of design error was common within the manual computation. A proven software will be able to virtually eliminate this as a problem. Fast computation has made it likely to execute multiple iterations of complex designs allowing optimization of solutions that were simply not attainable previously. The expeditious exploration of tremendous design options will lead to improved product performance. Furthermore, complex problems computer modelling process has led to more creative and imaginative structures [1]. A computer never gets tired and it does work faster than human and performing everything similarly every single time

which this indicates a quality control since the design process can be standardized to a certain degree [2].
As for more advanced automation in design which is available nowadays, it brings up possibilities to evaluate the life-cycle impact of initial design decisions and consider the long-haul sustainability objective of buildings starting as early as at the design phase [6]. While in regard to sustainability which is the current demand for building construction to date, automation can assist in the aspects of sustainable design [5]. With automation, it let the computer do the time consuming regular work and frees up time for the engineers for more creative development work [2]. In regard to the availability to generate various design options and allowing design optimizations, it can allow the reuse of successful solutions instead of recreating the wheel for each project [1, 2].

2. Automation in Civil Engineering Design in Assessing Energy Efficiency

The construction field has become more and more advanced in digitalisation as internet technologies and other information technologies are being implemented. Automation in the engineering field is not at an infancy stage as it has been implemented by engineers since the beginning where computer-aided modelling and simulation was at its beginning [2].
In line with it, global warming and its significant climate changes are endangering the human existence [9]. Currently, the trends in global energy usage have brought up serious questions over the difficulties with supplies, the depletion of energy sources, and severe environmental impacts. In accordance with the International Energy Agency (IEA), total world energy demand has inclined by over 46% from 1971 to 2010. Furthermore, the total carbon dioxide emissions (CO_2) along this period inclined by 48%. Due to the consequential global warming and climate changes, the global energy demand is soaring. It is once stated, "global energy demand will increase by one third in the period of 2012 to 2035." British Petroleum (2013) also foresees that world primary energy usage will increase by 1.6% per annum from the year of 2010 to 2030 [10]. The building sector was discovered as the biggest contributor to energy consumption, which it takes more than one-third of all total energy and one-half of total electricity consumption worldwide [11].
With the growing threats of global warming, fast technological and rapid economic development, Architecture, Engineering, Construction and Facilities Management (AEC/FM) is now beginning to emphasize the importance of energy efficient buildings to be developed [12]. Therefore, energy analysis has become one of the important parameters of building design, and it is gaining more importance as energy crises and global warming is becoming worst by day [13]. Traditionally, in order to analyse building energy efficiency, the data required to be integrated in different stages and different specialities. However, it is difficult to analyse building energy efficiency based on 2D design. First of all, traditional energy consumption analysis needs a lot of professional data, complex input, and professionalism. In addition, it is difficult for a designer to spend a long time to study simulation software of energy usage and to analyse the energy consumption for every phase. Therefore, the energy consumption analysis is arranged in the last stage of the design, where the analysis results are very complex to apply in the architectural design stage [14].

2.1. Application of Automation in Civil Engineering Design in Assessing Energy Efficiency

In regards to that, a lot of software vendors/manufacturers have invented energy simulation systems that can be utilized to evaluate the efficiency of a building virtually [12]. A rapidly developing technology that has been demonstrated and proven to be able to help to build energy performance analysis thus achieving a more energy efficient building is Building Information Modelling (BIM) [9]. BIM allows for all sorts of information to be gathered and embedded in one model, which include structural, mechanical, electrical, plumbing and lighting [12]. It can minimize information losses since the models and information ideally should comply with the whole building process and only be created once. A standardized BIM platform for information consist description of terminology and related terms, processes and shared information and how the data that have been generated are stored and structured. The neutral format IFC (Industry Foundation Classes) works well with BIM since it gives the ability to link to different software systems to let the information travel through the process [2]. Many research have been carried out in the recent years attempting to which extent by linking a BIM model with an energy analysis software/tool would be benefited in delivering energy efficient buildings.
Sadeghifam *et al.* in [11] and Abanda and Byers in [12], both have conducted case study by linking BIM model with energy simulation software for the purpose of building energy analysis and to assess how BIM implementation can be utilized to facilitate the process. Sadeghifam *et al.* on their study have focused on assessing the efficiency of different types of wall materials with regards to their properties on energy saving, while Abanda and Byers were focusing on the impact of the orientation of building on energy use. Sadeghifam *et al. and* Abanda and Byers in their case studies have utilized Autodesk Revit for BIM model which is linked to Autodesk Ecotect and Green Building Studio respectively as for the energy simulation software. In order to analyse the building energy consumption, both studies have created the model by Revit which is then saved as a gbXML file before it is imported to the energy simulation software for energy analysis. Sadeghifam *et al.* in their case study on a four-storey library at UTM, Johor have tested on some variables of wall materials and have recorded the trend of variations to choose for the most optimized wall materials. It was discovered from their results that the modification on the type of wall materials input in Ecotect software assisted to approach in electrical energy saving by 8% [11]. Whereas Abanda and Byers in their case study on a three-storey house that has performed energy analysis based on changes in orientation of building have discovered that a well-oriented building could save a possible £878 worth of energy along its lifetime [12]. Both investigations thus have been successful in demonstrating that building orientation and types of wall materials impact energy use and therefore improve the energy efficiency of the building. They have also agreed that BIM application has aided the process of the energy analysis to consequently optimize the energy usage of the building [11, 12].
Recently in 2017, several studies have been conducted on the implementation of BIM linking to energy simulation software for energy analysis. Guan *et al*. in [14] have proposed a method to analyse the building energy conservation using BIM platform in their case study on 29 floors Zhonghai international community, Shenyang which was emphasized on the building air conditioning system. They established the BIM model using Autodesk Revit which later on the gbXML format is exported to Ecotect software to analyse the solar radiation and the building energy consumption. The energy simulation resulted in the energy consumption of the building air conditioning system from month to month which can be used to optimize the building energy usage [14]. Jangalve *et al*. in [13] have studied residential building analysis using BIM technology. The study was conducted using Revit for the preparation of the model, which is then exported to Autodesk Green Building Studio by gbXML file for the energy simulation. Several simulations have been conducted for the energy analyses which include CO_2 emission, monthly cooling load, monthly heating load, monthly fuel consumption, monthly electric consumption, the annual wind rose, and humidity. It was reported that the application of BIM technology along with green building services available in Revit, has led the energy analysis process of a project to be done easily and accurately [13].

Meanwhile, in the same year, Samuel *et al.* in [10], Li and Xie in [15], and Gourlis and Kovacic in [16] have also explored the potential of the modelling, analysis and optimization of building energy efficiency using BIM and energy simulation software. Samuel *et al.* have carried out an in-depth analysis on Arboleda Open BIM project in Santa Domingo using Vector Works Architects (BIM software) linking with IESVE software for energy simulation which had resulted to the delivery of the world's first energy building [10]. While Li and Xie, and Gourlis and Kovacic have conducted their studies using the same software for BIM which is Autodesk Revit, linking with Autodesk Ecotect (or uploaded to Green Building Studio cloud) and EnergyPlus with OpenStudio Plug-in respectively for energy simulation purpose [15, 16].

Various simulations can be performed in the energy simulation software after the file is exported from the BIM software. Based on their study, it is believed that by linking a BIM model to energy simulation software, it brings tremendous sustainable advantages in building energy performance analysis. Furthermore, it also improved the design's team ability to assess the design assumptions and make well-informed decisions [10]. Based on their findings, Samuel *et al.* in [10], Li and Xie in [15], and Gourlis and Kovacic in [16] are all agreed that the approach did not only accelerate the energy simulation process in achieving the energy saving design in an earlier stage but also assisted in achieving a more detailed and accurate results. However, Gourlis and Kovacic have discovered that the process from BIM to energy analysis software in many cases needs manual corrections at the middle stage of transition that can affect the simulation input data [16]. Guan *et al.* in [14] have reported the problem occurred during the data conversion from the BIM model where the conversion will lack some data that influence the analysis. Nevertheless, BIM technology can be used to enhance the green building performance, thus help to reduce the building energy consumption [10, 13-16].

Jalaei and Jrade [5] have also proposed an advanced and improved method that connects BIM with energy analysis. The disparity with the previous researches explained in this paper is that they had also linked the proposed method with cost estimating tools and green building certification system in order to assist designers to prepare for sustainable design at the early stage. An actual project which is a three floors office building project located in Quebec, Canada was used to prove and validate the capabilities of the proposed method. The method initially started by gathering information related to green materials, such as the materials used, and potential LEED certification points, before storing them in a database that can be recognized by BIM's tool. From the initial phase, more than 80% of the components utilized in the project had their LEED certification points. After linking customized BIM tool (Autodesk Revit) with the energy analysis tool (Ecotect Analysis), designers were able to assess the model in accordance to different green building rating systems. This study has resulted to a calculated potential number of 44 LEED points. The earned LEED points are only based on three criteria of the LEED system. This method intended to assist construction players to design for the sustainable building, analyse the building energy, and evaluate the environmental impact at initial stages [5].

2.2. Adoption of MyCREST in Civil Engineering Design to Achieve Energy Efficient Building

MyCREST stands for The Malaysian Carbon Reduction and Environmental Sustainability Tool. MyCREST is aimed to integrate sustainability impact indicators with carbon indicators in a building. The MyCREST system differs from current sustainable building rating systems in regards to the basic methodology of pursuing assessment and certification. It is made of basic 'tools' – which is the most fundamental tool in MyCREST. It combines these basic tools in order to develop a 'scoring plan,' which it will be used to evaluate a building for certification. The tools are namely the design, construction, and operation and maintenance. Each tool is the 'star' rating for each stage of the project. MyCREST awards different star rating to the different phase of the project and will award an overall star rating. By this way, all the three phases in the project will be evaluated. These scores are then 'combined' based on a weightage to make up the full scoring plan for overall rating by the MyCREST certification [22].

Focusing on the design tool according to the needs of automation in civil engineering design, it evaluates the 'design stage' of a project. For this stage it consists of criteria and sub-criteria. Each sub-criteria have varies points with the range up to 40 points with Energy Performance sub-criteria (EP) as one of the criteria which has the highest number of points. The aim for energy performance impacts is to reduce a building's energy consumption and carbon emission significantly above the baseline without neglecting the thermal comfort of the building [22]. A computer simulation model will be utilized to evaluate the energy performance and identify the energy impact. This model will quantify energy performance as compared to the baseline building. A building is considered not to be sustainable enough if it is not energy efficient [23]. In regard to that, BIM is known has broadly been adopted by the building industry due to its ability to avoid creating mistakes to be encountered at the early stages and assist in scheduling and sequencing the construction accurately, identifying conflicts, assist in design alternatives, and facilitating the selection of appropriate solutions for complex projects [24]. Furthermore, BIM tools have the capabilities to allow users to try-out various alternatives of energy saving at the initial design stage by depleting the time-consuming process of re-entering all the information necessary for a complete energy analysis [24]. In addition, it was also proven that BIM technology can be utilized to improve the green building performance which the energy analysis process of a project can be done easily and accurately, thus help to decrease the building energy consumption [10-16]. Incorporating sustainable design strategies with BIM technology has the potential to enhance the traditional design practices and to effectively lead to a high-performance design of proposed buildings [5].

3. Artificial Intelligence in Enhancing Automation in Civil Engineering Design

In line with the evolving technology on the market to date, artificial intelligence (AI) is an infancy technology that is currently in the market to revolutionize and improve the construction industry. Processes of operating machinery, modelling and estimating, and BIM are just a few of many fields in construction which are available to enhance production and efficiency with the utilization of AI [17]. Traditional methods for modelling and optimizing complex structures systems need huge amounts of computing resources [18]. Artificial intelligence allows hidden insights into data that humans cannot process or will require too much time. AI utilizes the machine learning to solve issues and conduct tasks with higher speed and accuracy [19]. Activities and tasks that complicate the construction process can now implement AI to make enhancement in productivity, safety, quality, and scheduling [19]. AI can be defined as an aggregative term to describe it as a machine copies human cognitive functions, for instances in solving problems, learning and pattern recognition. AI is capable of machine learning where algorithms are utilized to equip a machine to learn from the data it's provided with. In the construction industry, the data resulted from images captured from mobile devices, drone videos, security sensors, building information modelling (BIM), and others have become a bunch of broad information. The construction sector has been adopting technology for capturing data. However, the issue to date is to implement a system that that has the capabilities to manage all these gathered information in order to be fully beneficial for both construction professionals and customers [20].

The construction industry is continuously trying to enhance and develop its performance and therefore they have increasingly utilizes computers and IT to assist in this [6]. Tizani and Mawdesley [6] in their study have made recommendations for future research to include in improving digital information modelling and expanding the standardized product and process modeling technologies; enhancing the capabilities of decision-support and decision–implication analysis by improving broader-aspects of the problem space; embedding optimization techniques more holistically; and integrating all of these by making more utilization of virtualization in an attempt to simplify the utilization of the output technologies [6]. Jalaei and Jrade [5] had actually aimed for their study to fully automate the whole integration process of BIM so users can evaluate LCE, energy analysis, LEED and cost estimation during the conceptual design stage. However, there are certain procedures need users to do several inputs manually, which make the method to be partially automated [5]. This is where the use of AI, as an expert system is believed could probably assist the method to be fully automated. In their study regarding design automation in construction, Sandberg *et al.* in [2] have suggested that different design automation approaches (BIM, master models (MM), knowledge-based engineering (KBE), configuration, modularization, platforms and simulation) can be connected and can be expanded with other approaches (e.g AI, genetic algorithms, fuzzy logic) to enhance the design automation process [2].

4. Proposed Flow Process Development in Assessing Building Energy Efficiency in Malaysia

Based on the literature reviews done on the automation in civil engineering design, it is proposed for the automation process to be enhanced by the implementation of artificial intelligence BIM to be linked with MyCREST, a green rating tool in Malaysia. The implementation of MyCREST in this process is mainly to assist in assessing building energy efficiency in Malaysia. The process of the automation is divided into five main steps. It started with the modelling of a building using BIM tool. Autodesk Revit has been utilized as the BIM tool by many other past researches due to its proven tremendous advantages. The BIM model will be linked with an external database in the form of 3D design families created which consist of information gathered on sustainability materials and components that can be recognized by the BIM tool. Therefore, the building model in BIM will be created not only based on existed BIM's database but also by referring to the external database developed. The BIM model created is then will be interconnected with AI BIM for sustainability evaluation as shown in Fig.1, the proposed flow process of automation in civil engineering design. The AI BIM in this process is a knowledge-based plugs-in developed in assisting the process of checking and decision making for sustainable building design. Therefore, any changes suggested by the AI plug-in will be directed back to the BIM model for modification on the model.

In assessing the building model sustainability, the data retrieved from the BIM model will be linked to the MyCREST certification module developed. At this stage, all the criteria required for the design stage based on MyCREST will be evaluated. The criteria to be evaluated include pre-design (PD), infrastructure and sequestration (IS), energy performance impact (EP), occupant and health (OP), lowering embodied carbon (EC), water efficiency factors (WE), social and cultural sustainability (SC), demolition and disposal factors (DP), and lastly sustainable and carbon initiatives (IN). Emphasizing on the energy performance impact (EP) criteria as it brings to the highest number of points which is up to 40 points, it is consisting of much sub-criteria need to be evaluated especially the 'required' sub-criteria, which it must comply for eligibility of certification. There are six 'required' sub-criteria need to comply which are building envelope performance, roof thermal performance, building energy efficiency performance, fundamental refrigerant management, commissioning of building energy system (for air-conditioned building), and energy performance-energy efficiency (for non-air-conditioned building). Particularly on building energy efficiency performance (EP Req3) sub-criteria, it can be complied by demonstrating 6% of energy savings as compared to the baseline building and by ensuring the thermal comfort parameters that comply with Energy efficiency and use of renewable energy for non-residential buildings - Code of practice (MS1525:2007). Meanwhile, there are another 12 sub-criteria for energy performance impacts which each of them carries vary number of points to contribute to the overall rating of the building. For instance, artificial lighting (EP4) sub-criteria carries a maximum of 4 points to the scoring.

After the building model sustainability is fully evaluated using MyCREST, the automation process will be considered as completed if the final evaluation outcome is made acceptable. Otherwise, if it does not satisfy the MyCREST conditions, the data retrieved will be returned back to AI BIM plugs-in for another cycle of checking and decision-making process considering other options of the building designs. The new decision suggested will leads to the modification on the database and thus will also modify the BIM model. Then, it will undergo the same cycles again until the building model evaluation result is made acceptable. Comparing the proposed flow process with a past study on an integrated BIM model in evaluating building sustainability done by Jalaei and Jrade [24], they evaluated the building sustainability based on LEED Canada green building rating system. They also had calculated the potential LEED points of the building model. However, the LEED points earned by the study were only focused on three LEED system criteria which are Energy and Atmosphere (EA), Materials and Resources (MR), and Indoor Environmental Quality (IEQ). Therefore, the potential LEED points earned does not indicate the finalized points that can be earned since they did not go through sustainability evaluation for all the LEED criteria. In addition, the integrated BIM method introduced for the study is reported as partially automated method due to some procedures need users to do several inputs manually. Whereas the proposed method for this study aimed for fully-automation procedures with the aid of the AI BIM plugs-in to assist in the decision-making process during the design stage.

5. Conclusion

In the interest of automation in civil engineering design in assessing building energy efficiency, the following conclusions were made from this study:

a) Building Information Modelling (BIM) is a rapidly developing technology that has been demonstrated and proven by the many past researchers to be able to improve building energy performance analysis thus achieving a more energy efficient building.
b) BIM platform is proven not only to accelerate the energy analysis process in achieving the energy saving design in an earlier stage but also assisted to deliver reliable, more accurate and more detailed results.
c) Artificial intelligence has been suggested to enhance the automation in civil engineering design. The expert systems can intelligently assist in the decision-making process, helps in the process of design optimization by reviewing and verifying designs, and offer engineers a tremendous set of knowledge.
d) A new flow process is proposed in automation in civil engineering design which is by using AI BIM to be linked with MyCREST, a sustainable building rating system in Malaysia in order to improve the design automation process in assessing building energy efficiency.

e) The AI BIM plugs-in is proposed to enhance the automation in civil engineering design to assist the decision-making process during the design stage. Therefore, it would assist the design engineer to do the building optimization as early as during the design stage.

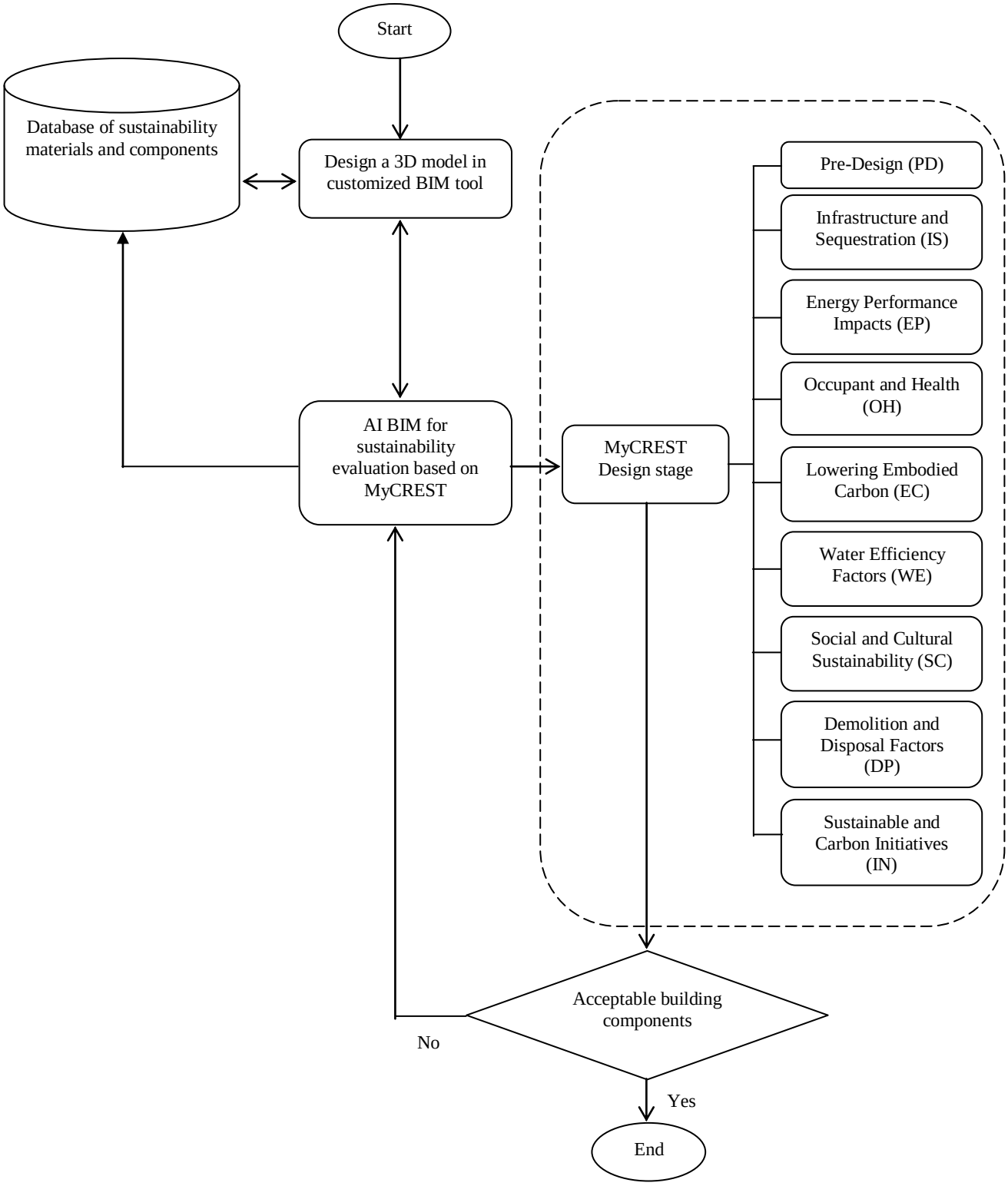

Fig. 1: Proposed flow process of automation in civil engineering design.

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