Prioritization of Industrialized Building System Components for BIM Applications

Saeed Banihashemi Namini [1+], Mahmoud Shakouri Hassanabadi [1], Yousef Karimi Vahed [2], and Mahdi Moharrami Meynagh[1]

[1] Department of Construction management, University Technology Malaysia

[2] Department of Structure and Material, University Technology Malaysia

Abstract. At the present time, construction industry is lacking information concerning predefined IBS geometrics and components which can be used in BIM. The aim of this study is to prioritize industrialized building system's components with reference to BIM principals in order to be integrated with BIM software packages. The Warszawski classification which is based on geometrical configurations, was selected as the target classification to be prioritized by using analytical hierarchy process. The results show that the most important categories to be integrated with BIM are "Planar or Panel System", "Linear or Skeleton System", "Box System" and "Industrialization on Site" respectively. The results of this paper can be used to develop some specific algorithms and frameworks for BIM to facilitate the process of design calibration and production of IBS components.

Keywords: BIM, Industrialized Building System, Prefabrication, Object Oriented Model, AHP.

1. Introduction

Construction industry is the second largest one in the world. It produces 30 percent of overall GDP within countries [1]. By advent of the industrial revolution in the 18th century, this field was transformed to a systematic and professional way, which had to consider parameters of industrialization such as speediness, thriftiness, mass production and providence. The creation of structural steel and reinforced concrete as the major materials used in the building sector, affected the trend of construction into more mechanized handling and large prefabrication of components. Subsequently wave, the information revolution with advent in the mid decades of the 20th century, has moved from the utilization of computers for storing, processing, transforming information and automation of industrialized processes. It had prominent impacts on the building phases such as design, construction and administration. It is evident that these two revolutions have caused the construction industry to be more technology-oriented.

Currently, modern IT based, mechanized based and software based processes and tools play an active and key role in developing construction industry. Industrialized Building System (IBS) is one of these technologies that as a direct result of industrial revolution, assists construction industry to be more efficient and productive. IBS is defined as a construction system in which components are manufactured in a factory, on or off site, transported and assembled into structure with minimal additional site work [2]. In general, IBS is a methodology which drives local construction industry towards the adoption of an integrated and encourages parties in the construction industry to produce and utilize pre-fabricated and mass production of the building at their work sites [3]. IBS employment causes projects to reduce wastage, diminish labor usages, increase equipment involvement and decrease completion time and costs by prefabrication of components, making systematic and mechanized building and using modular coordination. Building information modelling (BIM) is another technology which integrates management paradigms such as critical chain project management, critical path method, lean and concurrent engineering with some software like Primavera, Revit, Navisworks, Echotech and etc. It is an exact representative from information revolution so that associates composition of processes to make, communicate, virtualizes, scrutinize, collaborate, coordinate and integrate building models.

[+] Corresponding author. Tel.: +60-177248796.
E-mail address: sbnseyed2@live.utm.my.

Although many researchers have studied Building Information Modeling (BIM) and Industrialized Building System (IBS), but these topics have been rarely studied together. Hence, there is a gap between integration and coordination of IBS into BIM. According to a research conducted by “Mike Kanaby” from “FMI Corporation” of “American associated of builders and constructers”, only 18% of respondents from AEC currently see BIM as very critical for prefabrication [4]. At the present time, the construction industry is lacking information concerning predefined IBS geometrics and components which can be used in BIM. The aim of this study is to prioritize industrialized building system’s components with reference to BIM principals in order to be able to be integrated with BIM software packages.

2. IBS Classifications

IBS has different classifications based on material, process and system. In early stages, Majzub [5] proposed a concept in classifying the building system. He explains that the relative weight of the components should be used as a basis for building classification which consists of frame system, panel system and box system. Another classification based on building systems was done by Badir Razali [6]. These building systems are namely conventional system, cast in situ system, prefabricated system and the composite building system. Each building system represented by its respective construction method which further characterized by its construction technology, functional and geometry configuration. Warszawski [7] classified the building system into a few types which depend on the particular interest of their users and producers. His classification uses construction technology as a basis for classifying different building systems. In this manner, four major groups can be distinguished such as system using timber, steel, cast in situ concrete and precast concrete as their main structural as well as space enclosing materials. These systems can be further classified according to geometrical configurations of their main framing components that are the linear or skeleton (beams and columns) system, planar or panel system, three dimensional or box systems and industrialization on site.

3. Research Methodology

With reference to BIM principals and this fact that BIM packages are object-oriented software, the Warszawski classification which is based on geometrical configurations, was selected as the target classification to be prioritized for BIM. Also, to cover the aim of this paper, quantitative method by focusing on distributing questionnaires based on analytical hierarchy process (AHP) was used as the basis for analyzing and weighting variables. AHP allows decision makers to model a complex problem in a hierarchical structure.

A total of 140 sets of questionnaires were distributed to the respondents by virtue of Google Docs package. 58 questionnaires were returned that is 41% of response rate. According to Fellows et al [8], the normal expected useable response rate is ranging from 25 percent to 35 percent. Therefore, the total response received is considered sufficient for the purpose of this research. Most of the respondents were from the faculties and academic staffs who are responsible for BIM and IBS research groups within pioneer universities. The architect / engineer / quantity surveyor / other technical staff consist of 34 percent of the total respondents.

This group of respondents is the frontline of the people who in contact with the design stage of the construction projects. Their opinions are very useful and provide true insights to this research. By targeting fields just within the scope of this study, IBS and BIM experts were set as fields of expertise for respondents in which 48% of respondents had only expertise in BIM, 36% had only expertise in IBS and the rest 16% had expertise in both fields. Figure 1 shows respondents expertise and their years of experience.

AHP application for this work included three steps in solving the decision problem:

Step 1: constructing the problem in the form of a hierarchical model

In this step, the problem (prioritization of IBS components) was broken down into smaller elements based on their attributes and development of a hierarchical model with various levels. For this study, a three

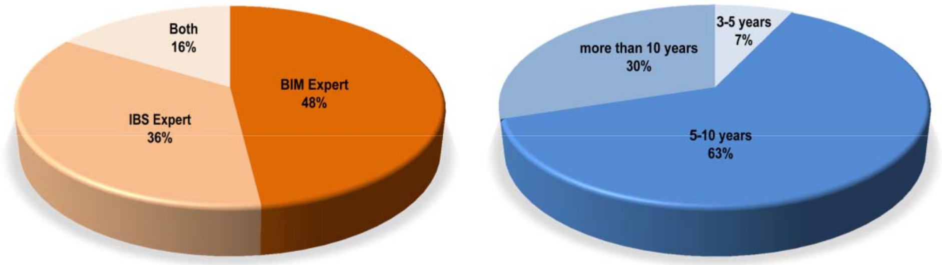

Fig. 1. Fields and experiences of respondents

level AHP model was developed in which, the highest level is the focus of the problem; the intermediary levels represent Warszawski categories and the lowest level includes components.

Step 2: making pair-wise comparisons and finding the evaluative matrix

The pair wise comparisons of the elements in a specific level are made in accordance with a particular element in the immediate upper level. For n criteria, (n2-n)/2 comparisons have to be made. Accordingly, to evaluate the weights of four categories, six pair-wise comparisons and to find the weights of the components within the categories of linear or skeleton system with 4 components, planar or panel system with 3 components, box system with 2 components and industrialization on system with 5 components, 6, 3, 45, 1and 10 pair-wise comparisons were made respectively. In order to convert the qualitative judgments into quantitative parameters demonstrating the weights of categories and components, the suggested scale by Saaty ranging from 9 to 1/9 was used [9].

Step 3: local priority and comparison consistency

Once the comparison judgmental matrix is available, the consistency of the judgments is determined and the local priorities of criteria can be obtained. Generally, a consistency ratio of 0.10 or less is deemed reasonable [9]. The consistency ratio for the comparison of the categories and criteria within the categories of linear, planar, box and industrialization on site systems were 0.005, 0.0004, 0, 0, and 0.0005 indicating high consistency in the judgments of respondents. Finally, collected answers were analyzed by "Expert Choice 11" which is the only AHP exclusive software.

4. Analysis and Discussion

As inferred from figure 2.a, the most important category is "Planar or Panel System" by obtaining 0.328 relative weight as compared to others. "Linear or Skeleton System" is the second priority with reaching to 0.289 point. "Box System" and "Industrialization on Site" are the third and fourth categories by 0.236 and 0.147 respectively.

There are many possible reasons to justify the highest significance of planar or panel system in order to be implemented in BIM software in comparison with others. BIM is totally an object oriented process. For this reason, all systems and construction elements, which are selected to be provided into BIM, ought to be capable of being converted into 3D objects. Panel systems, among Warzawski IBS classifications, are the highest qualified category in terms of this characteristic because panel systems are usually composed of single elements and consequently, the dimensions of them can be readily identified. The dimensions of planar components are determined by their support system, by the layout of enclosed spaces, and by other architectural design features which quietly can be predefined. As well, probably the most widely used types of prefabricated system are those employing planar or panel-shaped elements for floor slabs, vertical supports, partitions and exterior walls.

Unlike linear systems, which are mainly employed as structural framing, planar systems also fulfill interior and exterior space enclosure functions. As the next category, the three-dimensional systems use box units that contain concrete walls and floors. The units can be either cast in boxlike moulds or assembled in the plant from panel elements. In both cases, their dimensions are determined by transportation and erection considerations. It is clear that these constrains don't allow to develop pre-defined BIM components.

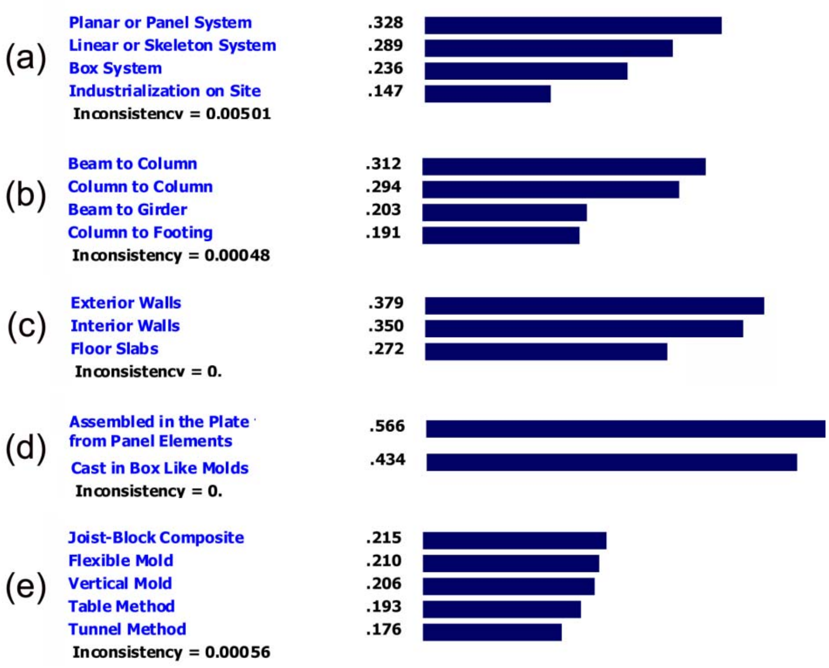

Fig. 2. Inconsistency and weightings of a)IBS Categories; b) Linear or skeleton system criteria; c) planar or panel system criteria; d) box system criteria; e) industrialization on site criteria

The same trend is valid also for the last category. A special group of systems often referred to as industrialization onsite, or simply as industrialized building, combines intensive utilization of various precast elements with highly rationalized framing construction methods.

Warzawski divided linear system components into four elements. It can be seen from figure 2.b that beam to column element of this category is the most significant and column to column, beam to girder and column to footing are the following components respectively.

Planar system components were classified into three major elements. By having a glance at figure 2.c, it can be deduced that exterior walls by reaching to 0.379 of relative weight is the most significant and interior walls accompanied by floor slabs are the second and third elements of this hierarchy. As previously stated, planar systems are excessively used in construction projects. The most novel prefabricated components such as walls and roofs have been manufactured in this division too. Among its components, panel walls have the highest proportion due to their flexibility in the dimension and size, erection, fabrication and the construction methods. Although there are numerous types of prefabricated floor slabs which are implemented and created, the wall components are allocated the majority of construction patents. These are some facts that support the respondent judgments with regard to current hierarchy.

Box system category is composed of two components (figure 2.d). An “Assembled in the plate from panel” element with 0.566 points is the first and “cast in box like moulds” by 0.434 is the second ranked components for this category. The key point of the reason for the significance of “Assembled in the plate from panel” is that this type of IBS is built from panel elements which logically increase the ability for converting and embedding into BIM packages.

The last and least ranked category contains of five main components. With reference to figure 2.e, “joist-block composite” with 0.215 points of relative weight has the first rank and flexible mould, vertical mould, table method and tunnel method are the second to fourth ranks respectively. Very often prefabricated elements are used in conjunction with conventional framing-concrete or steel. Typical elements used for this purpose are modular hollow core slabs, Tee beams, thin membrane plates, girders, exterior walls and stairs. Systems using these elements combine flexibility and the monolithic nature of conventional framing with saving in formwork, masonry and various finish works substituted by prefabrication. The main reason for this group to have the least significance among categories is due to its assembling and fabrication nature which makes it incapable of converting to digital matrix of data.

5. Conclusion

The industrialized building systems can be automated now by means of information technologies. Implementation of computer tools such as computer-aided drafting, computer-aided engineering and especially computer-integrated prefabrication brings the new brand ideas to promote the precision and quality of the construction prefabrication. In conclusion, the most important categories are “Planar or Panel System”, “Linear or Skeleton System”, “Box System” and “Industrialization on Site” respectively. There are many possible reasons to justify the highest significance of planar or panel system in order to be implemented in BIM software in comparison with others. BIM is totally object oriented process. For this reason, all systems and construction elements, which are selected to be provided into BIM, ought to be capable of being converted into 3D objects. Panel systems, among Warzawski IBS classifications, are the highest qualified category in terms of this characteristic because panel systems are usually composed of single elements and consequently, the dimensions of them can be readily identified.The results of this paper can be used to develop some specific algorithms and frameworks for BIM to facilitate the process of design calibration and production of IBS components.

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