# **Evaluation of the Application of Building Information Modeling Technology in Intelligent Architecture Realization**

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#### Abstract

One of the best and newest methods in increasing productivity in architecture and designing the buildings, whether from optimum scheme and timing or the costs is using the system of building information modeling (BIM) in designing and conducting the projects. This system is a hierarchy of architecture and intelligent designing according to the three-dimensional models which improve the whole cycle of the longevity, qualitative and quantitative values. BIM definitely has found its way to architecture and building industry and is improving gradually. Building information modeling helps the architects and engineers to achieve their goals in building and structural projects. This system provides a brand new way of designing: providing the design by means of intelligent elements, which is the final product of an intelligent building information modeling and its application in designing the buildings, the effect of this system on achieving the intelligent architecture of building is investigated. The results of study shows that by using BIM system from the initial stages of designing a building and using intelligent elements, optimal operation in intelligent buildings can be observed.

Keywords: Design, intelligent buildings, architecture, building information modeling

# Introduction

One of the main indices of the architecture projects are different changes that happen at all the stages. These changes may vary from study phase to design phase and can happen at any project. The main reason can be the result of the different decisions made by different people who have a role in conducting a project. These decisions only consider their own part and do not pay attention to other parts' needs, thus, they may lead to inconsistency of different parts of a structural project. This inconsistency not only does result to disagreement, but also wastes the energy, time and cost and will lead to low efficiency of the project. Therefore, if we can use an organized and intelligent structure such as Building Information Modeling (BIM), these problems are solved and the performance is improved and consistency between different elements of the project is boosted and the efficiency hopefully increases. Intelligent buildings can be of the newest products of the information technology in constructs, which in this study, the system of Building Information Modeling will be introduced and, the effect of this system on achieving the intelligent architecture of building is investigated. For serving this purpose, first some key concepts regarding to new modeling systems in constructions and intelligent buildings will be introduced and we will continue the study with some examples of intelligent construction designs by means of BIM system.

# **Building Information Modeling (BIM)**

According to the U.S national standard union, information modeling (IM) is the algorithm of the existing data in a pattern including" digital presentation of physical features of a design and is a function of common facilities in all the involved processes for achieving a complete information regarding to forming a reliable and fundamental center for decision making in all the entire design life cycle" (Smith, 2007).

Modeling is repair, reconstruction, renewal and monitoring the contractor, the facility services, evaluation, designing the construction projects which in general concept is known as "building information modeling" or "building algorithms" or "complete configuration of the constructs" which is called Building Information Modeling or in short BIM and shows the modeling the related information of a building which in recent years, has found its way in academic debates related to building making and has improved significantly. According to the definition of a collection of data which describes the construction and maintenance of a building in its life time, a subcategory is related to systems base on BIM. BIM systems completely cover the geographical data, the relation of distances, geometrical data, features and abilities of a building, usage data, maintenance and other related data. In other words, BIM should cover all the related abilities and capacities of a building in its lifetime. Generally, the formation construction of a building and the materials used in it and all the data related to its facilities are two main issues that are defined in form of BIM. Three indices of architecture, engineering and construction (AEC) which have always been separated have been gathered together through time and provide same needs. This has led to saving time and budget in civil projects and will effect positively on improving the quality of building industry. Building information Modeling is a new term coined by AEC and models the construction three-dimensionally (Kymmel, 2008). Building information Modeling (BIM) is a sample of the newest 3-D models in order to simulate the planning, construction and utilization in civil projects that is used in many developed countries in building industry. In fact, it means instead of using the common cartography, a sample of 3-D model including spatial, situational and temporal design is used and will be chosen amongst the groups involved in civil projects and its main role is providing coherence amongst different teams during the construction. This system helps architects, engineers and contractors to first build the final construction in virtual environment and solve the probable problems at any stage of construction like designing, conduction or utilization.

The concept of BIM mainly means the formation of digital 3-D concept of a building and representation of its natural features. Building information modeling is a process and the application of virtual designing and construction of a project during its lifetime.

Generally, the system of Building information modeling can be introduced in a way that: BIM adds the components of 3-D modeling with specific feature to the 2-D cartographies and their features. The specific feature is that each member of the design in BIM has the 3-D physical feature and an array of the activities and responsibilities of the construction management. These pieces of information are related to the lifetime of the project from beginning to end and consist of:

- Justification phase to conceptual design
- Study of the first and second phase
- Preparation
- Construction and installation
- Initiation
- Utilization and end of the project

# **Designing in Building Information Modeling**

The concept of BIM is beyond CAD and BIM model is actually a model according to database. In BIM, the designing process of a model starts with intelligent components which represent the door and windows, air conditioning system, wiring, etc. These components know themselves and their exact relation toward other components. Therefore, the designer and conductor does not need to rummage too many plots for getting a piece of information on a particular component such as window and its size, material, glass, wood, etc. and can refer only to the component itself. The component has all the information regarding to its features and can adapt itself to any changes that

happens to its nature and to the new design. BI works as the central core in producing buildings and their related agents such as architects, civil engineers, mechanical and electrical systems, producers and conductors and finally, owners as the peripheral elements and are in correlation with each other (Leicht and Messner, 2007).

A model of BIM not only does bring the intelligent relation amongst different components of a design, but also brings the possibility of examining different designing scenarios for all the groups in a virtual manner. For example, one of these scenarios can be the rotating model of the construction and examining the amount of energy consumption according to different angles of the solar radiation. Also, other designing groups including the facilities can apply changes in their models and see the effects of these scenarios on the architecture of the project and finally, the contractor can virtually analyze matters such as sequence of conduction, efficiency, construction and installation during the designing and developing the schemata. In the 3-D and 4-D modeling system, construction is considered as the central core which can work independently and other elements related to buildings (such as ceiling, windows, doors, stairs, etc.) are considered as the dependent variables and work peripherally to the central core (Leicht and Messner, 2007). In other words, by means of this state -of- art technology, the building is defines as a complex of stuff which has the ability to change in 3-D. therefore, BIM saves all the related information as a central core and lets the dimensions and components of the building be related to each other. BIM system conducts the constructional project in a virtual environment. By means of BIM technology, an accurate virtual model of a digital building will be made. At the end of the modeling, the virtual model consists of accurate geometry and related information for utilization, and construction can be used to materialize the construction. A sample has been shown in below figures.



**Architectural Model** 

**Plumbing Model** 

Structural model

Figure 1. Building information modeling system for project the Hilton Aquarium, Atlanta, Georgia, USA (Holder Construction)

# **Intelligent architecture**

A building owns intelligent architecture if it has sensors that stimulate system to respond the stimulations (Oster Hoiz 2002). The source of stimulation in architecture goes back to art. In the early 19th century, artists tried to build sculptures that have moving organs. Spiritless happiness sculpture by Daniel Roussin in 1999 is one of the kinetic sculptures that electronic technology has been used in it. Also, kinetic arts in architecture has been used as artistic masterpieces and sometimes in buildings (Lazovik et al, 2009). Kinetic architecture can be seen In gipsy's' life as

well. Their tents are movable structures that can be packed and carried. Kinetic structures are portable and flexible structures in kinetic architecture. Fox (2000) defines kinetic architecture as: a construction with variable situation and variable and kinetic geometry. He has defined kinetic systems which one of them was flexible system. Therefore, the concept of kinetic architecture is not mainly an intelligent concept but brings the connotation that ability can control the construction and move its different parts.

# **Intelligent building**

Nowadays, constructions are kind of technology. They adapt themselves with technology and its use. As the buildings acquire the ability of the computes, they become intelligent. The first intelligent building used technology for bringing safe and convenient and energetic environment. The idea of an intelligent construction pays attention to the link between accessibility, enlighten, safety, monitoring, management and telecommunication. Being coherent gives permission to systems to exchange the data amongst each other. The exchange of data amongst system causes the output, which is the final result, happens with no interference. On the other hand, output or the final decision makers are the respondent systems that present a suitable response for the data entered to system from various sources. Output of the information and decision maker systems are two main components in this type of architecture.

The concept of intelligent building is somehow a give and take and strong and accurate exchange of information amongst different parts of the building. Correction of different parts of the building includes all the parts -Parts such as HVAC, mechanical parts, Accessibility control, safety, management, lighting, maintenance and repair, local networks and energy management,- that have a role in building. Intelligent building means control and management of the parts of a building by users who use computer abilities to fulfill the needs-that can be efficiency, profitability, saving energy, amusement, welfare, returning the investments and reducing the life expenses.



Figure 2. Intelligent building

Therefore, there is no need to correlate the definition of an intelligent building to successes and ambitious goals, because this definition may change according to the situations and people. An intelligent building should have the same performance in order to respond to different and various needs.

Scholars have defined "intelligent building" as a building that the latest technology has been used in it. With this, it is clear that they call a building" intelligent", when it owns the most up-todated constructional systems. Although innovation is of utter importance in intelligent buildings, it does not mean that we call them intelligent merely on their information exchange and system coherence.

The international symposium of architecture in 1985 in Toronto has acknowledged that "an intelligent building is a combination of innovation –weather they are technological or not- with perfect management which reimburses most of the invested money. This definition not only does emphasize on the necessity of innovation and use of technology, but also reminds us that one of the goals of building intelligent constructions to bring back most of the expenses. It may seem as if these goals are considered only in commercial and clerical buildings not residential ones, unless that are considered for commercial and clerical buildings are not mentioned in above definition. A clear definition on intelligent building is the one that boosts the efficiency of its residence and make the effective management possible, according to special conditions and for the least cost. Efficiency and profitability are somehow subliminal and invisible and they cannot be achieved unless paying attention to the past and making some comparisons amongst them. Also, reducing the expenses is among the goals that should be considered by control systems.

In 1996, Bob brought up a definition for intelligent buildings:" a building that uses modern technology to control the different components automatically." This definition clearly shows the information exchange procedure among the controlling and controlled components in an intelligent building. Building commanding procedure has been mentioned in DEGW's definition. This definition says that an intelligent building is way more responder to its users' needs and has the ability to adapt to new technology. This definition includes a very important issue on Building commanding procedure.

#### Sensors in intelligent architecture

Speaking of intelligent architecture, the starting point is sensors. Sensors are tools that gather interior and exterior information. In interior spaces, they collect the exterior information in specific time intervals. Sensors are like neurons of a building that can sense the special situations and decide upon the internal and external situation (Wong, 2005).

Generally, sensors are divided into three groups and internal and external sensors are subcategories of these groups and they can be explained like below:

- 1. Safety sensors which are at service of interior and exterior environment, such as fire and smoke, entrance and exit, flutter and acceleration, and CCTVs
- 2. Sensors related to weather quality control, such as temperature, humidity, sun rays, air pressure, and amount of light
- 3. Monitoring sensors such as building system sensor, surveillance on mechanical system

# The use of BIM in intelligent design

The development and production of computer model is used for planning, designing, constructing and conducting a model, building information modeling (BIM). The obtained model from BIM is an enriched model of data, objective, intelligent and parametric and its indices and

visual output are specialized to answer the various users' needs. The user can derive the needed information and therefore can achieve the decision making and boost the process and examine the facilities. An essential difference between BIM & CAD2 is that in 2-D CAD models, a building is described by two independent dimensions such as plans, façades and levels. The correction of each dimension needs reviewing and updating the other indices. Therefore, it makes an erroneous procedure that itself is a reason for the final version of the building. Further these data, some sketches are only graphical like line. Circle, arc, and in contrast, the BIM model is an intelligent and contextualized model in which objects are defined according to the conducting the construction systems such as spaces, walls ,columns, pipes, and ducts.

BIM model owns all the information about the building such as physical-operational features and its lifecycle intelligently. For example, an air-conditioner in BIM model has data related to blowing, operation, maintenance procedure, the airflow rate and its cleaning conditions.

BIM model has the geometry of the building, spatial connections, amount and the feature of the components of the buildings, approximation of the costs, material list and projects' tables. Furthermore, this model can show the whole lifecycle of the building and therefore, the features of the materials can be obtained easily and fast from BIM and also the limitations and different parts of the operation can be isolated and redefined. Systems and orders can be shown as a scale to all or part of the facilities of the building. Also, construction document such as designs, details, suggested procedures and other features can relate to each other easily.

#### BIM applications in order to provide intelligent building design

Generally, the list below is the most important functions of BIM, which has an important role in design and construct of the buildings .

- 1. Intelligent visualization of the design
- 2. Optimization of the design
- 3. Bringing a schedule of timing and the hierarchy of the construction in initial designing
- 4. Approximation of expenses
- 5. Integration of the intelligent design information
- 6. Coordination amongst systems especially intelligent ones.
- 7. Utilization and maintenance
- 8. Recovery and improvement of the buildings

#### Designing Optimization for smart buildings with BIM

During any design process, the architectural team needs to track various design options until enough information is available to decide between them. For example, an open office scheme providing day-lighting and views may need to be tracked with a more partitioned layout for programmatic and environmental comfort purposes well into the documentation phase. These two options could then be used for detailed day-lighting design analysis. Building information modeling with Revit Architecture supports design optimization by letting architects develop and study multiple design alternatives (green or not) simultaneously within a single model. Design options can be toggled on and off in the model for visualization, quantification, and analysis as needed, and can be maintained for as long as required (which sometimes can be quite late in the design process) and then incorporated, discarded or archived as key design decisions are made. In this fashion, what-if analyses examining different sustainable design options for varying levels of LEED certification (or alternate ways of achieving the same level of certification) can be easily examined and thoroughly documented within the Revit building information model - keeping good ideas on the table as long as required for evaluation.

#### Visualization for smart buildings with BIM

During the Middle Ages and into the Renaissance, master builders designed and built their projects using on-site, life-size models (i.e., the actual built project). As the centuries passed, those processes that were used to create St. Peter's Basilica and Notre Dame Cathedral evolved into what we now think of as the design/construction process, where architects – separated from the construction process – uses two-dimensional drawings to visualize and document their design. BIM allows architects and engineers to become "digital" master builders who are able to see the building, its materials, its structure, and its performance in real time as it's being designed, and (more importantly) before the design is converted to very expensive bricks and mortar – or more likely metal studs and gypsum board. At the same time, this model can very efficiently provide a fully coordinated set of conventional documents that is accurate and reliable.

This is the power of building information modeling with Revit Architecture, and is critical to many aspects of successful sustainable design. The building information model can be used in conjunction with software tools for energy analysis, lighting studies, and so forth, to quantify the green effects, while 3D visualization and walk-throughs allow the design team and the client to see the greener design.'

#### **Day-lighting**

Day-lighting, the practice of using natural light to illuminate buildings, not only makes people more comfortable and productive, it can sharply reduce the electrical lighting load and subsequent heat and energy loads. A sustainable, high-performance design can derive much of its ultimate success from effective relationship to, and integration of, the sun's energy into the design of the building envelope and fenestration.

However, effective day-lighting is rarely performed due to the complexity of formulas required to accurately analyze day-lighting characteristics. There have been computer software programs available for years that can accomplish these tasks, but the cost to use them was prohibitive because of the cumbersome and difficult methods for entering the building design information. Revit Architecture changes this by allowing the design team (rather than expensive lighting labs) to undertake the modeling, measurement, and documentation of complex interior day-lighting designs within their standard design environment.



Figure 3. Example of visualization solutions, visualization and Visualization of High Buildings by using BIM



Figure 4. Taking advantage of daylight by using building information modeling

#### **Energy Analysis**

According to the Department of Energy, there are more than 76 million residential buildings and nearly 5 million commercial buildings in the United States today. The beginning of this white paper contained a remarkable figure relating to those structures that bears repeating: buildings consume close to 40 percent of all energy used in the United States. Contrast that figure with the amount of energy consumed by SUVs, mini-vans and light duty trucks on the road (approximately 7 percent) and one can see that scolding SUV owners for depleting our oil supplies might be considered a tempest in a teapot. Sophisticated energy analysis is critical to a building design strategy for reduced energy consumption. And, like software for day-lighting analysis, energy analysis programs have been available for years, but rarely used by the design firm. Many firms outsource energy analysis (due to time and cost), and as a result building energy performance information is available only at fixed points in the project, usually later than needed for supporting the best decision-making about the project.

But now, Revit Architecture provides robust design information with the necessary level of detail and reliability to complete these analyses earlier in the design cycle, and makes possible routine analysis done directly by designers for their own baseline energy analysis. Revit Architecture is linked directly to the Green Building Studio<sup>TM</sup> (GBS) service from GeoPraxis (www.geopraxis.com), an industry leader in the development and implementation of building energy analysis tools and web-based solutions. The GBS service creates a geometrically correct thermal model of the building, applies local building code assumptions, creates a DOE-2 input, runs the analysis, and returns summary results to the designer's browser.

In this fashion, energy analysis can be performed throughout the design process. In early design phases, massing studies can be used with resulting energy analyses to make decisions about how the building is placed on the site. As the design progresses, various day-lighting options can be evaluated for energy savings. When appropriate, the DOE-2 model input files can be used with engineering analysis systems such as eQUEST®, EnergyPlusTM, or Trane® Trace® 700 for detailed analysis. This automated input of geometric coordinates can save hundreds of hours of manual labor.

# Smart design with Building Information Modeling: The process of expanding from 3D to computable nD

The utilization of Building Information Modeling (BIM) has been growing significantly and translating into the support of various tasks within the construction industry. In relation to such a

growth, many approaches that leverage dimensions of information stored in BIM model are being developed. Through this, it is possible to allow all stakeholders to retrieve and generate information from the same model, enabling them to work cohesively.

Building Information Modeling (BIM) is defined as "a digital representation of the physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition." Many terms related to BIM have been adopted by researchers, such as virtual design and construction (VDC) and multi-dimensional (nD) modeling. Table 1 lists some of the widely used terms in both research and industry studies and shows a summary of them by application domain.

A BIM model is different from traditional 3D CAD models in which 3D CAD only describes a facility with independent 3D views, such as plans, sections and elevations. If one of those views is modified, the others must be updated accordingly. Further, data in 3D CAD drawings are only graphical entities, such as lines, arcs and circles. On the contrary, a BIM integrates semantically rich information related to the facility, including all geometric and functional properties during the whole life cycle in a collection of "smart objects". For example, a valve or tube module within a BIM would also include its functional and performance properties, such as material, supplier, maintenance requirements, cost and delivery time, in a semantically rich way. Each component is a "smart object" with all associated parameters stored in it. The information of the properties can be accessed when needed by any stakeholder. This important feature of BIM allows stakeholder access to information and combinations of information to which they have never before easy access.

As for other terms, virtual reality (VR) provides a toolwhich allows a user to experience a computer-generated simulation of a real or imagined environment (Whyte et al, 2000; El-Ammari, 2006). 4D modeling utilizes BIM for project time allocation and construction sequence scheduling simulations while VDC is becoming a more accepted industry term to explain the use of BIM to design and construct a project (Will Ikerd, 2013). In terms of nD modeling, some researchers use nD to describe the different maturity levels of BIM (Khoshnava et al, 2008).

Sample	Informatio	from 3D	Design review	construction	Management	constraints	Maintain
terms	n can be	building	Performance	process	of site		facility
	retrieved	elements	simulation				
			Virtual				
			simulation of				
3D CAD		✓					
Virtual				✓	$\checkmark$		
reality (VR)							
4D modeling	<ul> <li>✓</li> </ul>			✓	~		
VDC	~	~	$\checkmark$	~	~		
nD modeling	~	~	✓	×	~	√	
BIM	~	~	$\checkmark$	✓	✓	~	

 Table 1. Differences between widely used terms and BIM

#### Intelligent Design with n-dimensional space modeling by BIM system

This section introduces the proposed BIM application framework, a research and delivery map of existing research and implementation projects which identify interrelationships between project domains and requirements for further knowledge acquisition. This proposed BIM application framework targets stakeholders to better understand the current state of BIM applications and future BIM implementation requirements.

A BIM framework must be comprehensive enough to address all relevant BIM domains and implementation challenges as well as to present key issues of project management in a systematic manner. On the basis of the definition of BIM, this application framework consists of three parts including project domains listed, stakeholders and phases of the project life-cycle. These are shown as the three axes in Figure 5.

A particular research can be put in this framework using one of these six options: single BIM application within a single organization through a single project phase; single application within multiple organizations through a single phase; single application within multiple organizations through multiple phases; multiple applications within a single organization through a single project phase; multiple applications within a single organization through multiple project phases and multiple applications within multiple organizations through multiple phases.



**Figure 5. BIM application framework** 

For example, as shown in Figure 6, "a1a2a3a4" represents the utilization of BIM for safety management from the owner's perspective, while "b1b2b3b4" represents the utilization of BIM for cost management from the perspective of different stakeholders, which are, in this case, the owner, the contractors and the supervisors, also known as owner's representatives. The "c1c2c3c4, d1d2d3d4" area represents the utilization of BIM for design review during the planning and design phases by different stakeholders. In this framework, application of BIM in the construction industry can have 6 different levels based on the project. management tasks that are aimed for, the project stakeholders that are involved in and the different phases that BIM is used in.



# Figure 6. Geometric interpretation of BIM application framework

#### Conclusion

Because of intelligibility of all the members of a BIM model and reduction of the error in human stuff, impeding the interference of the different components in operation, increasing the safety of job and crew, the possibility of making change in the project architecture and the possibility of testing different assumptions in a project is amongst the benefits of the BIM modeling, which can define the final result of the project regarding to its needs and therefore, brings a qualified product, which, intelligent building is one of these products:

To sum it up, the results of the study show that a BIM model can be used for these objectives:

- Suitable design
- Revising the standards
- Management, approximation and reduction of expenses
- The sequencing of the construction
- Effective and fast procedures
- Better services for costumers
- Data for lifecycle
- Databank and building components
- Saving the conducting time of the project
- Increasing the safety of construction
- Decrease the claims

An intelligent building is a building that can respond to its users' need according to the processed data by the various inputs. The responding factor in a specific time interval in buildings is of utter importance. Different receiver and transmitter pieces of equipment are received according to internal and external changes. Also, it is noteworthy that one of the components of an intelligent building is the ability to learn. Before constructing an intelligent building, systematic planning plays an important role in order to reach your goals. The true need for having an intelligent building can be unfolded by the results and whether this need will be removed by constructing a building or not. Take utilization of the factories as example. The goals of the intelligent building construction almost cover all the aspects of human life. Utilization, like high efficiency, energy saving, entertainment, safety, convenience, decreasing the life costs and increasing the lifetime of the building all are amongst the goals achieved by constructing the intelligent buildings. An intelligent construction should have a neuron system which includes sensors and stimulators which control information in accurate and correct time. A building can operate static or dynamic. Therefore, changes of the internal and external structure are amongst the abilities of an intelligent building. Neuron system of the building is responsible to coordinate the systems in order to make the construction flexible to have a suitable reaction in environmental changes. As a human, users of the building should understand that it is happy or sad, sick or energetic. On the other, the building should understand its residence to act regarding to their feelings. It's clear that responsible architecture plays an important role in building spaces. Architecture and spaces should both have some feature to remove the needs of the users. Intelligent architecture by means of BM is not restricted to one or two of these reactions, but it should include all the static, dynamic, internal and external reactions.

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