Is BIM Big Enough to Take Advantage of Big Data Analytics?

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ABSTRACT

As the Architecture, Engineering, Construction, and Facilities Management industry undergoes a profound change with Building Information Modeling (BIM), it seems the right moment to properly re-structure the inherent processes to promote a new wave of innovation. To leverage digital information from each individual project into business value for the whole industry, researchers must borrow knowledge and solutions from computational fields, such as Machine Learning, Artificial Intelligence, Data Mining and Data Science. They will provide a guide to the development, and even transformation of current BIM processes, with potential for development of new tools and automation of many tasks. What is not entirely clear is if BIM could take advantage also from Big Data Analytics, as some professionals are been advocating. In this paper, the author analyzes Big Data problems and the BIM context, and argues that BIM could not immediately take advantage from Big Data-infrastructure. Nevertheless, a route of development is suggested, which extends BIM from its predominantly building-focused models to models that encompass an entire city, which certainly will demand Big Data Analytics. Thus, a new City Information Modeling seems to be the right path of development for BIM as it turns to be integrated with Geographic Information Systems and will lead to tools that would be adequate for future Smart Cities planning and management.

Keywords -

Building Information Modeling; Big Data; Machine Learning

1 Introduction

As the Architecture, Engineering, and Construction (AEC) industry undergoes a profound change with Building Information Modeling (BIM) [1], which actually is centered in information and communication technologies (ICT), now seems the right moment to properly re-structure its inherent processes to promote a new wave of innovation.

Much of the promised revolution attributed to BIM are still to come true, in part due to a lack of specific technologies that are already applied in other areas or industries [2]. In addition, the very organization of the AEC industry is slowing down such development [3].

To leverage information and automate specific workflows for whole performance upgrade, it is necessary to go further, and incorporate knowledge and solutions from fields like Machine Learning, Artificial Intelligence, Data Mining, and Data Science. They will provide a guide to the development, and even transformation of current BIM processes, with potential for development of new tools and automation of many tasks.

As data and information (and its flow through inter-disciplinary processes) are the essence of BIM, they would take an even larger part in the future, as BIM continually develops itself towards the incorporation of different Data Science techniques to extract the most of the industry assets. In this scenario, some researchers started to speculate about the use of Big Data Analytics in BIM processes.

In this paper, it is presented an analysis of the nature, amount and complexity of information presented in BIM throughout its lifecycle, and in Big Data problems. The comparison leads to the belief that present BIM models and processes would not take advantage of the necessary Big Data-infrastructure.

Nevertheless, in elaborating this analysis, it turns out that Big Data Analytics would be essential if BIM development follows one currently possible path to extension and incorporation of an entire city. This new City Information Modeling seems to be the perfect tool for dealing with future Smart Cities.

In the following sections, the role of analytics in BIM is highlighted. Also, Big Data Analytics is presented in such a way as to separate the kind of data encountered in Big Data problems, and the type of analytics that could transform data in information and knowledge. Next, the BIM context is also presented and compared to demonstrate that as it is, BIM could not take advantage of Big Data Analytics. It concludes with the proposition to extend BIM to Smart Cities, as it could be leveraged with Big Data Analytics. Finally, some conclusions about this research and future work are presented.

2 The role of analytics in BIM

Today, the paradigm of BIM is dominated by ICT. Many experts emphasize the role of Information in BIM processes based on the necessity of feeding information earlier in time when compared to traditional processes. The information comes from different professionals and, many times, concurrently. The BIM workflow that involves modelling assumes a technological (virtual) environment for collaboration and integration of all the information gathered or generated in the process. In reality, actual BIM software ends up only managing the information regarding the process of building modeling.

But analytics can also play an important role in BIM. A step further in introducing computational expertise in the AEC industry is to employ knowledge and tools from other fields, like from Machine Learning, Artificial Intelligence, Data Mining and, Data Science. The principle is to transform information, to discover knowledge, to better predict outcomes, to automate processes and analyses, and to optimize decision making.

Informally, Machine Learning is a field from Artificial Intelligence; and Data Mining, a field from Machine Learning; Data Science is very correlated with Machine Learning and Data Mining, but, for example, do not consider agents as Artificial Intelligence does [4].

There are many models, techniques, and approaches from those fields that could be immediately applied, and already are in many research works, that could bring advances to BIM. For example, if it is desirable to automate the process of creating as-built (modeling over point cloud data in BIM authoring tools) [5], a software must be able to classify clusters of points in construction elements. For classification problems such as this, there are many different mathematical models that could represent the problem at hand. The difference among them is in the richness of the dependencies modeled against the difficult in applying reasoning methods to a complex structure: Support Vector Machines (SVM) [6] for instance, do not model interrelated cases (a cluster of points will be assigned a certain class regardless the class of the cluster in its vicinity); and Conditional Random Fields (CRF) [7], which could represent many possible complex dependencies between data observed in the model (it is more likely that adjacent clusters receive the same class or label). These two mathematical models are the state-of-the-art techniques in the field of Machine Learning.

There is also a division that groups the different techniques or models: probabilistic approaches, logical approaches, and a combination of both [8]. Inside probabilistic approaches, which are more adequate to real-world situations that deal with uncertainty in data, there are two basic types of models or graphs: directed-acyclic graphs (Bayesian Networks - BN), where there is an implicit cause-effect relationship between variables, and, undirected graphs (Markov Network - MN, Markov Random Fields - MRF, CRFs), that model spatial relationships without an explicit representation of causality. Those models could also be separated in generative models, focused on explaining the dependencies among data, or discriminative models, focused only in finding their labels [9]. The model type impacts supervised learning algorithms performance, and modeling characteristics.

Logical approaches, that although could produce some benefits [10], normally cannot deal with the amount of data existent in real-world problems.

Some models from Machine Learning are already applied in the AEC industry. For example, there is a survey on the use of sensors in construction sites to monitor construction machinery using Radio-Frequency Identification (RFID), computer vision based sensors, sensor fusion, and Global Navigation Satellite System [11]; clustering of real objects to classes of abstract objects for reducing computational cost in simulation of interference [12]; shape mining approaches to design [13]; use of image classification for construction materials [14]; use of SVM for classification of materials in construction [15]; development of automatic design and planning of scaffolding systems [16]. In addition, the application of AI in construction was the subject of another survey [17].

There are many initiatives in the research literature that brings computational field techniques to BIM processes, and it is only the beginning of this trend. Many more will appear in the near future, as BIM continues to demand more performance from its tools.

3 Does Big Data analytics fit in BIM processes?

Big Data has been a popular trend in the business news for some years. The dependency on information and its value for BIM processes have made some people to suggest the application of Big Data analytics to the business of the AEC industry [18, 19]. Nevertheless, one might ask: does Big Data analytics really fit in AEC processes?

The relevance of this question is in the fact that such implementation would demand many resources such as machines, cloud services, software, and expert people. Moreover, the field of construction already passed through a period of investment with BIM technology and processes. Although BIM already shows the payoff [20], it is important to analyze if the mentioned benefits of Big Data applied to BIM could not be obtained with other kinds of Data Science techniques, which will not cost as much as the required Big Data infrastructure.

Firstly, Big Data Analytics must be more precisely defined and characterized, for answering that question.

3.1 Big Data Analytics

Data Analytics, or Data Science, are techniques where mathematical models from given phenomena are not available, but where patterns that characterize them can arise from available data and that, therefore, could be used instead of a formal model [21]. Those patterns bring value, and lead to the transformation of data in information, and then into knowledge, which could be used, for example, for predictions in many businesses.

Big Data Analytics follows the same principle, but are very particular in terms of the data available. Although there are many different definitions or uses for the term, Big Data comprises data that cannot be dealt with traditional software and that could not even be stored in a single machine.

3.1.1 Big Data

Data, in a Big Data scenario, have some particularities. Traditionally, it is characterized by their Volume, Velocity, and Variety [22]. In other words, data is acquired constantly so that it, due to its huge amount, becomes difficult to store and process. It comes from different sources and, in many cases, is not structured and must be transformed and labeled to be useful in some way. Additionally, Veracity [23], Value and Variability are also used to characterize it [24].

CERN [25], for example, deals with a volume of the range of 30 petabytes of data produced annually and in a velocity of approximately 600 million times per second, due to the time of occurrence of collision between particles. Maybe, the variety is not so apparent but comes from different sensors (the variety in Big Data problems is primarily linked to unstructured data coming from social networks, internet data and sensor networks). Its scientific findings could not be achieved without special infrastructure linked to Big Data Analytics.

That kind of data, which does not fit in tables, normal databases cannot handle properly, and it is necessary to use software and techniques like Hadoop, which is the most popular implementation of MapReduce [26], to process it in parallel, and in heterogeneous networks.

3.1.2 Data Analytics

There are two distinct kinds of data analytics: predictive and descriptive [4]. The difference between them is that in predictive analytics there are some categories in the problem at hand that one wants to attach to the data; and, in descriptive analytics, one is most interested in finding patterns and creating groups with similarities to have a better understanding of the scenario.

Predictive Analytics often deals with problems that involve supervised learning [21]. In supervised learning, the problem pattern is discovered/created in a training phase, where a training set is supplied by a user, with corrected labeled data, from which a generalized data set it will be formulated. For this kind of application, it is essential having a reasonable amount of data, both regarding volume and case variability. For this kind of analytics, there are problems with continuous variables (regression) and discrete variables (classification). With classification, it is possible to solve binary and multi-class problems.

Descriptive Analytics treats the problem of unsupervised learning, when there is no predefined variable to find, but one is interested in measuring how similar an object or case is to another. It can be split in three types [4]: *association rules*, where it must detect frequently occurring patterns between items; *sequence rules*, where it must detect sequences of events; and *clustering*, where it must detect homogeneous segments of observations.

3.2 BIM and the building lifecycle

To find out if BIM processes could be framed as a Big Data problem, it is important to characterize data in BIM models.

Data in BIM models regards information about all the lifecycle of a building: design, evaluation, planning, construction, operation and maintenance, and even demolition or retrofit. Nowadays, BIM is most used for design, evaluation and planning [3].

Most of the data processed by BIM software tools are structured. Aside for references to product catalogs, and text descriptions of entities in the models, all data in BIM fit inside a schema of objects from the construction environment: a Site, a Project, a Building, a Building Floor, a Wall, a Task, and so on.

That structure represents part of the semantics involved in the design of a building, as it facilitates the process of information sharing. BIM models do not have complete semantics [10, 27], but most of the data pieces are already classified in one or another class from the data schema.

Although each software vendor has a proprietary BIM model format, currently there are a standard (ISO16739: IFC - Industry Foundation Classes) [28] that is used as an intermediary model in transaction-exchange between tools for different purposes.

If data regarding BIM models were used in Big Data Analytics, the base unit of information for the algorithms must be a single BIM model, which could be separated in more than one file (normally each discipline of a building comprises its own file).

Thus, taking a typical BIM model it is possible to analyze its volume or size, its velocity of acquisition or completion, and its variety.

In the range of volume, Aconex [29] states that the size of BIM models has doubled in average in the past five years, to 54 MB in 2013. It has stored around 270,000 models in its management service, which gives, say, a repository of 14.5 TB. Large projects generates models between 300 to 600 MB, and with other data linked to BIM models, it easily comes to 1 GB [30].

Given the numbers, a single BIM model, even incorporating more geometric details and specifications (higher LOD) and information from other processes of the lifecycle of a building or general construction, is not sufficient to take advantage of Big Data. It would be necessary to have a repository of BIM models, for example from an architecture office, which could be mined for information extraction, like design solutions, so that the volume of data handled could justify Big Data infrastructure.

The range of variety could not be considered in the BIM model per se, as geometry and other properties from objects, and general process information barely could take advantage of Machine Learning techniques. Approximately, 60% of BIM data is geometry, and 40% are related to properties, attributes and relationships between different objects in the schema [1]. So the data is largely structured. The variety in the BIM context could be aroused in Facility Management, in the operation of a building, where the building would have many and different sensors, and employees log in a certain amount of data based on occurrences in a day-to-day task.

Also, the range of velocity only starts to makes sense in Facilities Management and operations or maintenance applications that should promote data acquisition from the real world into BIM models, with sensors that could characterize building performance in real-time. However, it still may not present enough and appropriate data so it could take advantage of Big Data analytics.

It seems that currently BIM processes hardly could take some advantages from Big Data-infrastructure. Although some examples of analytics were applied to the AEC industry, they do not deal with Big Data.

However, in the process of analyzing the appropriate use of Big Data Analytics in the AEC industry with BIM models and tools, a possible path of development for BIM was elaborated, and it could really take enormous benefit from Big Data.

4 Extending BIM towards Smart Cities

As BIM is consolidating itself in the AEC industry, and more workflows of the lifecycle of a building are been handled inside BIM tools, there is a constant drive to extend its models and tools in different directions.

Following a comparison between Product Lifecycle Management (PLM) and BIM [31], the latter could be extended in the direction to become a tool or environment of development and management of product models. It is the path of the current philosophy of the BIM.

Other efforts, that focus in interoperability of the data model, or the seamless ability to different software exchange information between one another, it must have to deal with the role and complexity in adding semantics inside BIM models [10, 27]. This path of development follows in the direction of more analytics in BIM.

There is even ongoing research on an official extension for IFC to introduce infrastructure [32]. So it seems natural that BIM could expand its scale of a single building and consider infrastructures of a city. To deal with infrastructure will demand integration with Geographic Information Systems (GIS) applications. In this direction, it could eventually leads to the extension of BIM to a digital or information model of a city. There are real potential of innovation in this concept of BIM associated with cities.

Take the new processes that emerge in construction with the advent of BIM models and its computational tools. Also, take the yet promised virtual environment and integrated design/evaluation with building simulation. Now, extends those concepts to a large scale, many buildings inside one model, and create model and tools to deal with infrastructure, a relation between locations or buildings, flow of information in real-time. It could become a Smart City Model.

In the scope of an entire city, there is no doubt that Big Data Analytics could be extremely powerful in bringing better planning and decisions in every related area. A collection of building and infrastructure models, providing many instances of the same object type (volume); real-time data, provided by an array of sensors inside buildings, and outside, in the streets (velocity and variety).

4.1 Recent advances in BIM/GIS Integration

A natural step in this direction is already in course. IFC, the neutral specification of BIM, currently in its 4th version, is being prepared to model tunnels, highways and bridges [33].

However, to deal with a city, unavoidable BIM must seamless integrate with GIS technology. Until a couple of years ago, GIS only dealt with 2D objects. Its focus always were to spatial analysis, based on surveyed data and statistics. That is the correct approach to a Smart City.

Clearly, there is an intersection between the objects of study of BIM models and GIS systems. Many studies do exist that proposes work to integrate both [34]. The principal difference between those data models are that BIM details one building and GIS represents information about a large area, with or without geometric, 3D detail of the objects involved.

The seamless integration of CAD/BIM with GIS system is far from complete. If BIM could ever play a role in Smart Cities, this integration must work. CityGML is only one of the proposed model of integration [35].

4.2 The concept of a Smart City

The analytics of interest in such a model of a city is for planning and management so that the people living in, and the very government body, could be benefited from an integrated and informed approach to decision making.

Smart Cities is a field of its own, although there is some conflicting terminology, where the correlated terms Digital Cities and Intelligent Cities appears and meant things entirely different.

One possible definition to Smart Cities is: "*Smart City is referred as the urban center of the future, made safe, secure, environmentally green, and efficient because all structures – whether for power, water, transportation, etc. are designed, constructed, and maintained making use of advanced, integrated materials, sensors, electronics, and networks which are interfaced with computerized systems comprised of databases, tracking, and decision-making algorithms*" [36].

In contrast, the terms Digital Cities and Intelligent Cities do not focus in the entirety of the problem of a city. The difference between them is not thoroughly agreed but one could understand that a Digital City is focused in network infrastructure to give large broadband access to government and population to connect one with another, and to provide services online. An Intelligent City is focused in having a 3D digital model of the entire city, like the Autodesk initiative [37] that leaded to the product Autodesk Infraworks.

In terms of analytics in data of the scale of a city, there is a field of research called Urban Informatics [38]. It is a trend that also correlate with Smart Cities, as viewed in the process of transforming BIM in a Smart City model.

The main difference between BIM and a Smart City, beyond of the scope, is that BIM is centered on information, and a Smart City must be centered on the flow of information (and resources).

For a Smart City, technology is not the most important asset, but the use of it for the purpose of better, or more rational, management and use of scarce resources. For example, the interrelationship between energy, water, and food production must somehow be established inside the system and produce better solutions for development.

Also, mobility and transportation is another feature of large scale cities. A mechanism for route planning that could avoid many variables based on historical sequences could be used to provide users of a better way to go to work or home. The platform could also plan routes together optimizing the general movement of the population, in real-time.

4.3 BIM extension

In terms of data, it seems that objects considered in BIM models and objects considered in GIS models can perfectly deal with objects existent in a city. There is only the problem in how to integrate those two models inside one schema, as there is some interpolation of concepts, and different geometric representation, and level of detail between those two models. Some research on the integration of BIM and GIS are related in the past section.

In regard to the system created, including tools to visualized and interpret the data, few researches focused on that topic, and those research are also related to BIM/GIS integration.

The term CIM as standing for a City Information Modeling already appeared in the past literature, but the content of such models are far from agreed. Some have a perspective that encompasses many visions of a city, from different perspectives [39]. Others are focused in the necessary tools to deal with the scale of the models [40]. And also there is propositions in the same philosophy of BIM, to achieve a CIM [41]. But here it will avoid any such term, and will prefer the more neutral term of Smart City.

Probably, the software solution for Smart Cities will diverge from the solution found in BIM software environment or platform. In BIM, there are practically one tool for each specific use: design, coordination, 4-D planning, energy analysis, structural analysis, and so on. For a Smart City, where the system would be in the hands of a government body, it will be more interesting to have all the solutions or application inside a common system.

In it, the software must be capable of modeling and visualization of an entire city. Currently, it is not a problem, maybe the scale will bring some difficulties, but the most important feature will be the automation inside. To take many aspects in a city planning, it will be necessary to integrate every discipline in a city perspective.

The simulation for a Smart City would demand a large hardware infrastructure. Topics like weather, traffic, healthcare planning, contagious disease proliferation, for example, could take benefits of an integrated approach but would necessitate the right amount of trade-off between how discrete is each unity of the model, and the richness of the phenomena inside it, or the computational power required would be of the actual supercomputers operating in the range of petaflops.

Another difference with current BIM software is that in a Smart City the input does not come only from professionals responsible for different disciplines in a project. It must provide access to the people like in a social network. The software platforms or web services for a Smart City must allow for citizen participation in political decision, as for regarding budget allocation to each sector of a city, or to vote in different landscape projects. It is a new dimension of the representative power of a population in the destiny of a city. How to visualize, analyze and weight the contributions must be carefully studied.

5 Conclusion

As BIM is centered on information in construction, and Big Data Analytics on extracting knowledge from information, it seems that to apply the last in the former could be a source of innovation in the area. However, as argued in this article, BIM is not big enough to demand any solution (hardware or software) from Big Data analytics. Neither in data volume, nor in different types of data, and nor in velocity of acquisition of data. The ordinary use of BIM is far from the scenario of Big Data problems.

In this article it was analyzed how is the data in Big Data problem, and the characteristics of the data present in BIM. As it is, BIM could, and have been, employ some kind of analytics, to promote automation, integration, or simulation of processes, improving the performance in real projects.

Nevertheless, if the BIM models and software tools could be upgraded in such a way to represent an entire city, then Big Data Analytics would be the right choice to tackle the problems aroused.

In Figure 1, it exhibit, informally, a measure of the distance between BIM and Big Data, in the space defined by data volume, velocity and variety. It considers that with only BIM models, it will hardly attain the necessary volume to exploit Big Data-infrastructure, and has not a compatible velocity or variety. With BIM applied fully to Facilities Management, dealing with the entire lifecycle of a building, its operation and maintenance, it could attain some volume, variety and velocity. But only with a model of a Smart City, it will become a Big Data problem.

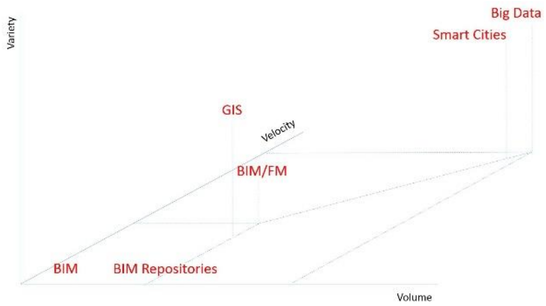

Figure 1 – Relationship of BIM models and Big Data Problems in the space of volume, velocity and variety. Source: Author.

It also shows the steps towards which BIM could be transformed in a model of an entire city, through integration with GIS models.

Big Data analytics seems perfect for Smart Cities planning, development and management, in a scenario where BIM and GIS models interact and share information to give a better view of complex situations.

Some directions were given to the possible extension of current BIM models and software. The combination of the detailed information management found in BIM tools and the spatial analysis of large areas found in GIS tools are the right advance to the integration of both in a system to deal with future Smart Cities.

Nevertheless, the tools and the algorithms behind it that would introduce Big Data Analytics in Smart Cities field are yet to be developed, and is a matter of ongoing research.

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