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Quantifying Values from BIM-projects life cycle with cloud-based computing

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Abstract: A variety of evaluation application and initiatives on the adoption of Building Information Modelling (BIM) have been introduced in recent years. Most of which however, focused mainly on evaluating design to construction phase-processes, or BIM utilization performances. Through studying existing publications, it is found that continuous utilization of BIM data throughout the building's life cycle is comparatively less explored or documented. Therefore, this study looks at improving this incomplete life cycle condition with the concept that accumulated BIM data should be carried forward and statistically quantified for cross comparison, in order to facilitate practitioners to better improve the projects the future. Based on this conceptual theory of moving towards a closed-loop BIM building life cycle, this study explores, through existing literature, the use of cloud based computing as the means to quantify and adaptively utilize BIM data. Categorization of BIM data relations in adaptive utilization of BIM data is then suggested as a initial step for enhancing cross comparison of BIM data in a cloud environment.

Keywords: BIM building life cycle; quantifying project-values; cloud based computing; evidence-based design and construction

I. INTRODUCTION

Building life cycle is pre-conceptually and could easily be mistaken as an open-loop system, due to the generically long lifespan of buildings compare to industrial products, factors of contextual or society change, and modification to initial intentions [1]. This is a condition where feedback of the end product is not being succeeded back to the creator. Take for example product design and manufacturing, the advancement of an end product greatly depends on the closed-loop system [1]. This is the feedback process where measures and reviewed data are fed back into the creation phase from the end users, forming a circulatory cycle than a linear process. Similarly in medical research new drugs proposal goes through a similar life cycle, the common four phases of clinical trails where Phase IV is the post-marketing surveillance feedback [2]. The essence is that, ultimately, the product is thus repeatable and modifiable. Feedback contains crucial information, which complements for modification of the next better versions.

Currently on building life cycle, it is perceivable that there is a loose and incomplete loop, between feedbacks from end users back to the creators' system. Building projects are mostly viewed as individual projects due to the range of variance. Thus apart from practitioners' experience, effort on captivation of quantifiable domain knowledge is rather minimal and is complex and difficult to achieve [1]. With the adoption of Building Information Modelling (BIM) for building life cycle, it is largely feasible to advance towards a closed-loop control for building life cycle to deduce quantifiable values from feedback and furthermore, acquire valued data from comparison between BIM projects.

Compared to a commercial product life cycle, building life cycle has much more bounded correlations and factors than mere target users to consider with. Therefore, to bringing about a closed-loop building life cycle with quantifiable feedback, the authors strives to comprehend quantifiable and adaptive utilization of BIM data in three levels of relations: relation between a building and its people (end users), its surroundings (contexts), and its city (network).

This paper presents reviews from existing research on building life cycle and cloud based computing to form understanding of the existing advancement of research towards BIM data manipulation. From the analysis of existing research, a categorization of quantifiable BIM data is then being presented as a proposal of thoughts under the concept of the closed-loop building life cycle.

II. METHODOLOGY

1. The authors conducted literature review to gain concise understanding and definitions on the topics of building life cycle, BIM data and cloud based computing.
2. Existing publications from the ASCE (American Society of Civil Engineering) database was then further analysed to grasp the current research trend and attempts. "BIM" "cloud" "computing" were used as search words, presented with 179 results. Titles and abstract were screened before retrieving potentially relevant full texts to be reviewed.
3. Identifying valid papers, topic relevancy and trend in relation to BIM data utilization based on cloud-based computing, the authors present the observance on BIM data manipulation.
4. The authors then further suggested a reorganized categorization to quantifying BIM data utilizing cloud computing.

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III. Literature Review

A. Incomplete Life cycle

To better understand the incomplete life cycle condition and move closer to a closed-loop operation, this section reflects the current research status through literature review.

It is essential to first look at the current understanding of the building life cycle flow. The following sequence of primary process description is the bases for building life cycle classification: *feasibility, design, construction planning, construction, operation* [1], and *renovation or demolition planning*. Minoring the optional phase of *demolition planning*, it could be understood that information is plateaued at the *operation* phase or as soon as the as-built status is reached. It is said that life cycle use of BIM in following through operations and maintenance phase still varies and is still an evident issue [3].

As evidenced by an analysis on BIM metrics from 41 valid peer-reviewed papers, it was reported that the smallest amount of only 2% of the results are about metrics measurement on facility management; while the greatest sector measures construction and fabrication phases [4]. Likewise, other notable initiatives developed by different institutes focus only on evaluate BIM performances in construction, such as the national BIM standard's interactive capability maturity model (ICMM), BIM excellence (BIMe) and BIM scorecard [5].

Therefore, as seen from the analysis above, the attention paid so far aims mostly at improving manufacturing and construction. Not only is the action of passing on the BIM feedback data is lacking, the facility's internal data has also yet to be better attended to.

The current incomplete building life cycle condition could be summarized as:

1. Underdevelopment of recorded and adaptive data in building life cycle *operation* phase in the current status of the industry.
2. Lack of feedback data as practice knowledge from as-built BIM facilities.

B. BIM: Project-to-Project Comparison

To assess and learn from the success and failure of a building project is a complex process and one effective way is through feedback comparison [1].

A great number of prior researches mainly demonstrate the benefits of BIM implementation by comparing BIM projects versus Non-BIM projects. Nevertheless, it is argumentatively more beneficial to seek BIM to BIM projects comparison than against non-BIM projects comparison [4]. This echoes with the idea of feedback data and comparison. By collecting BIM data feedback into relevant database, adaptive utilization is made possible as to quantify success and failure through data comparison and further more enables relative comparison between facilities.

C. Utilization of Cloud Computing

As compare to the traditional method of deduction, the authors view that utilization of cloud based computing and BIM would facilitate a closed-loop building life cycle and enables cross-project data comparison, as described in the previous section.

Cloud Computing:

Cloud computing is understood as computer resources virtualization; whereby the common supply of configurable resources such as storage, applications, network, and services can be obtained remotely on-demand, and the user client relies little effort in resources management and minimal service provider interaction [5] [6].

In the architectural, engineering, construction, and facility management (AECFM) industry, cloud computing mainly adapts as *Software as a* Service (SaaS), and *Infrastructure as a* Service (IaaS) service model.

SaaS relates to application services that are distributed through the Internet. Users can only access the application via the Internet and has no control over how the application is deployed on the backend [6]. One of the advantages of SaaS is that applications could adopt the pay-by-use model contrasting from the traditional pay per license software acquisition [6].

IaaS allows greater configuration for users to gain access to storage, processing and networks etc. [5]. The benefit of IaaS lies in lowering the acquisition costs of computing hardware. Users could conveniently purchase and acquire the right of use of more resources from providers for certain computing-intensive tasks, without investing more on physical hardware.

Cloud Computing in BIM:

Despite the small amount and relatively new initiatives, the following examples of existing research display the feasibility in utilizing cloud computing in finding underlying relations within BIM data to promote cross-project comparison.

Building information modeling cloud score (BIMCS) [5], is one well-structured example of cloud-based application for BIM performances benchmarking. They key utilization of cloud computing in this application-development initiative is: after collects data from users online input to form a database, the system improves based on the amount of accumulated data available. As enough data is accumulated in the database, data mining analyses on the benchmarking system will be carried out repeatedly [5]. Eventually through repetitive processing, the system could generate an unbiased benchmarking system and this based on building the application as a cloud based framework. Moreover, the application is designed to deploy as community cloud with *SaaS* service model. This technically allows only for domain-related practitioners to securely transfer data at ease without complex manipulation to the system [5].

Similarly the ongoing research of the web-based Structural Analysis Platform [7] utilizes cloud technologies to develop a generalized platform to tackle computing-intensive engineering problems. This initiative brilliantly combines individual machines into a grid-based workflow to aid processing and managing intensive amount of probabilistic structural data [7].

Further exploration of data input and data processing of BIM with cloud computing is demonstrated in a test bed of web-based platform for energy analyses data exchange [8]. It is attainable to deploy the web-based application for IFC (Industry Foundation Classes) files provisioning by using a NoSQL database to support visualization [8].

Another initiative of BIM cloud framework [6] compares and describes different level of virtualization, from cloud function being within the software application, within vendor platform, such as Autodesk A360, to high system and virtual machine control, which is less directly applicable for the AECFM industry [6].

From these initiatives, it could be understood that the main advantage of incorporating cloud-based structure along BIM is the capability to allow for a rapid and adaptive processing system to overcome data complexity and to find underlying relations within data, as to achieve cross-project comparison.

D. Analysis on Categories and Trends of BIM data research

To unfold in greater length of the relevant initiatives on BIM data in relation to cloud based computing, the ASCE database[3] was used to conduct the analysis by the search words "BIM" "cloud"[4] "computing". Having screened the titles and abstract relevancy of the 179 results given, 45 papers were considered potentially relevant and were retrieved as full texts to be analysed.

Key Findings:

As few as 8 papers are identified as being on topic and formative; another 26 papers contains information that is useful and relevant to BIM data manipulation. The 8 papers range from 2012-2014 year of publication. This suggests that research in particular to BIM data processing with cloud computing in BIM-field of study is fairly recent and only a handful of implementations [5] [7] [8] have been demonstrated elaborately.

From the database search results, 22 of the papers mainly refer to point-cloud and sensors configuration and application. A good number of researches directs towards as-built data. These papers are still considered relevant to an extent as they all commonly deliver research on BIM data manipulation. Subsequently, it can be deduced that the topic of study within the BIM filed and the current main trend falls into the sub-category of I. Surveying and Point-cloud data, II. Sensors and Performance data. Research in both categories span from pre-construction phase to as-built state.

Findings Summary:

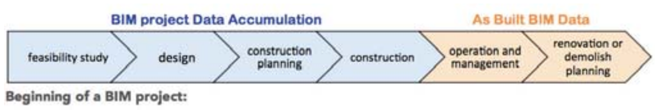
From the literature review and ASCE database analysis, it could be understood that BIM data is most actively being utilized and evaluated up to the as-built phase. Data manipulation in the *operation* phase is only being explored to a certain extent and mostly saturated within the use of building's internal maintenance as seen by the multiple instances of sensors and point-cloud research. From the literature review, the problem reckoned is that BIM data and project knowledge is not being carried forward or revitalized in any means.

IV. TYPOLOGICAL AND QUANTIFIABLE VALUES FROM BIM-PROJECTS

A. Closed-loop Building Life cycle

This unfortunate state of BIM data elapse, BIM data and project knowledge not being revitalized, leads to a lack of quantifiable domain knowledge. Given the vast amount of attributes and relations within BIM data, and little attempts in implementation initiatives as mentioned in the previous section, the problem of a non-clear structure for plausible revitalization and comparison is identified.

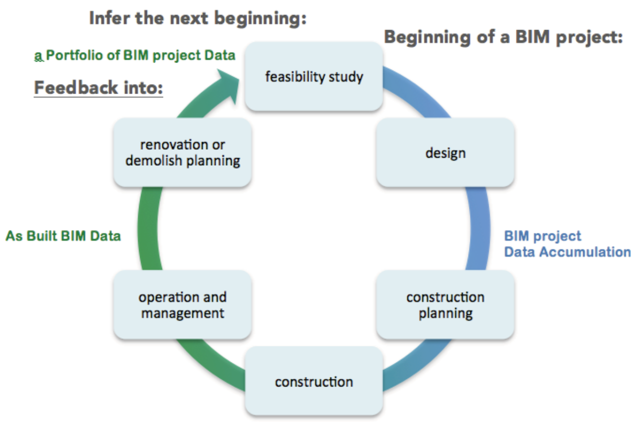
Taken from the present and typical ideology of building's life cycle flow, a conceptual closed-loop flow diagram of building life cycle is suggested [1]. In the traditional processes of building life cycle, BIM data remains dormant after having reached as-built state [Fig.1a]. It could be seen as a successive, single-directional, end-point oriented flow. Contrastingly, the ideal flow is a closed-loop system that allows BIM data to be brought back to its the creators as accountable feedback data [Fig.1b]. This unleashes the potential of inferring the next project with useful data information through accumulation of a database portfolio of BIM projects.



[Figure 1a] Traditional building life cycle flow [1]

[3] The ASCE database was chosen to be the desired research platform due to the number of search results presented compare to other platforms (Taylor&Francis Online, Architectural Science Direct, and Science Direct.

[4] Results of the search word "cloud" was slightly interfered with results relate to point-cloud. The authors persisted to include all possible results of cloud technology, cloud based and cloud computing etc. Therefore did not confine the search word to "cloud computing".



[Figure 1b] Ideal building life cycle flow

B. Quantification of BIM data

From the conceptual flow of closed-loop life cycle, there is a need to address the structure for accommodating the multiple spheres of BIM data, in such way that it could be read as feedback data and be revitalized as accumulative domain knowledge.

As observed from the paper review in the previous section, the main trend of BIM data manipulation is loosely dominated by Surveying and Point-cloud data and Sensors and Performance data, with research attempts throughout pre-construction phase to as-built state. However, BIM data also includes model, costs, energy data etc. For this reason, the authors reconsidered the chronology to address different levels of adaptive utilization of BIM data. This is followed by suggesting a categorization for quantification of BIM data.

Categorization for Quantification of BIM data:

From the closed-loop life cycle bases, the authors observed two main category of quantification of BIM data, namely: Properties Comparison and Relations Comparison. [Fig.2] shows the key categories of BIM data quantification as suggested.

1.) Properties Comparison and Relations Comparison:

Properties Comparison mainly concerns with the BIM data of the building's properties, compositional comparison between BIM projects.

Relations Comparison is further broken down into three levels: End User-level relations, Contextual-level relations, and Urban-level relations, which would be explained in the next part.

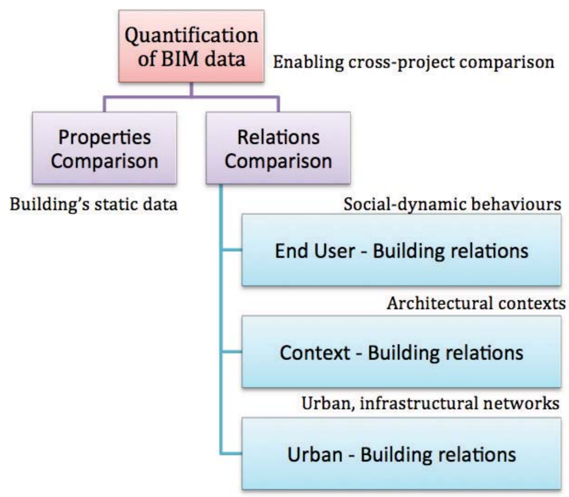
This categorization aims to facilitate the process of feeding quantifiable BIM data into a portfolio of cumulated BIM project data. On this note, it should be made clear that the main focus of this study is on understanding and quantifying BIM-architectural domain knowledge and not the advancement of BIM tools or processes proficiencies.

2.) Three levels of Relations Comparison

End User-level relations relates to end user feedback. This includes performance data of tracking users from within the facility, traditionally called post occupancy evaluation (POE), and target usage versus actual conditions. The importance of this relation aspect is supported by the relative analysis results about sensors and performance data mentioned in the previous section. End User-level relations closely relates also to cross-comparison of BIM projects vs. BIM projects mentioned earlier on. Given different projects with the same functional properties but varies in building properties, users data provide a means to better understand spatial configuration.

Contextual-level relations and Urban-level relations both require incorporation of geographical information systems (GIS) and 3D point-cloud. Contextual-level relations looks at the relation to the surroundings of a building. Site context and restrictions registered during *feasibility* phase is one of the starting points to that. Mostly the importance of this category is only identified in BIM renovation and retrofit projects and merely in new built. Nevertheless, until the *operation* phase, influence of the building to the surroundings and to people's behaviour exists especially in the prolong lifespan of buildings. Therefore it is valid to consider contexts in relation to buildings.

Lastly, Urban-level relations deal with network and regional information. For example infrastructural and transportation network pattern, and public facilities' inter-correlation.



[Fig.2] Key layers identified for Quantifying BIM data

C. Quantification of BIM data with Cloud Computing

In order to integrate multiple layers of instance relations as mentioned above, the authors view the necessity to deploy a similar model as the BIMCS [5] and the web-based Structural Analysis Platform [7] have delivered. Therefore to further develop and implement the overall scheme stated above, use of cloud-based framework is necessary. By using cloud, collecting and processing of the categories of quantification of BIM data would be feasible, as seen in the grid-based workflow example [7]. With accumulated BIM data, cross comparison could be manipulated by deploying a similar repetitive comparison workflow as the BIMCS [5] has demonstrated.

V. Limitation

This paper is an initial step of the research exploring the topic of BIM data revitalization in building life cycle. These levels of relations mentioned above only exist loosely as key topics within this study. Further investigation of the relevant data collection method mentioned, such as POE and GIS with practical examples and case studies, is needed to support each categorized layer. Examples of cloud computing in BIM should also be continually explored to deepen the understanding and technical knowledge towards possible implementation.

VI. Conclusion

This paper reveals the possibility of enhancing building life cycle towards a more closed-looped system similar to the commercial product life cycle. Evidenced through existing research, the problem of lacking continual data feedback in a complete building life cycle has to be addressed for the better of future projects as the bases of quantified domain values. Addressing this could further enables the possibility of comparing project values across BIM projects, breaking off from the present majority of comparing BIM tools and processes. Under this situation, the authors also reviewed example of using cloud-computing technology in BIM to reveal feasible integration. Subsequently, the authors identified and suggested layers of plausible comparisons as a category of data relevance, on the bases of employing cloud based computing. This categorization distinguishes firstly the building's static data, following by data relations. Relations are further on broken down into three layers towards users, context and urban.

1. *Properties Comparison* as in building's static data
2. *Relation Comparison* as in data relations
    a. *End User – Building relations* refers to social dynamics behaviour
    b. *Context – Building relations* refers to architectural contexts and immediate surroundings
    c. *Urban – Building relations* refers to urban and infrastructural networks

This is a first step within the study to speckle possible expansion of this topic that could be further developed into a framework and trial implementation in the future. Ultimately, by regarding to these conditions on quantifiable data of building's relation towards various spectrum, in particular emphasis from a social-dynamics, users-oriented point of view, the authors hope for a potential impact and extension on the ideology of BIM implementation as an evidence-based design and construction process for architectural projects.

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