Key Indicators for Evaluating BIM Collaboration Performances.

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Abstract: The accelerating adoption of BIM (Building Information Modeling) is challenging collaboration practices established in the construction industry. The implementation of BIM involves changes in participants work, organization, processes and collaboration methods. Therefore there is a need to be able to measure effectively and accurately collaboration, in order to analyze and determine current practices and their performances in organizations (company, team project) as well as changes required. Previous researches scope from evaluating BIM maturity of an organization to BIM collaboration requirements but lack of proper tools and methods to analyze collaboration performances. This is especially true when it comes to evaluate the efficiency and collaboration performances of processes rather than systems or organizations. Thus this research aims to analyze systematically and comprehensively previous researches proposing diversified methods to evaluate BIM performances and collaboration. Furthermore it aims to suggest key indicators to evaluate collaboration performances of processes and project organizations. This research may contribute to better understanding of collaboration performances within organizations using BIM and further development of evaluation method for analyzing BIM design project.

Keywords: BIM, collaboration performances, metrics, design team

I. Introduction

Construction projects have a multidisciplinary nature, which necessitates the involvement of many individuals and entities with various expertise. The fragmented structure of the construction industry, its various cultures and techniques have negative impact on its productivity and quality [1]. Building Information Modelling (BIM) will change this paradigm by gathering all actors of a project around a centralized, computer-based model. Implementation of BIM involves changes in project's participants work, organization, processes and collaboration methods [2]. It is expected to improve collaboration and information sharing between participants. However the complex nature of the construction industry leads to interoperability problems and hinders the full deployment of BIM.

BIM Collaboration Systems and interoperable formats such as Industry Foundation Classes (IFC) have been developed to mitigate these problems. Although these technologies could drastically enhance BIM adoption rate and BIM performances, it is not the level of technology used among parties that determine project success. Rather, empirical research findings have reinforced the importance of collaboration within multidisciplinary teams and the need for project team partners to collaborate, particularly in construction and BIM projects. Therefore it is important for project teams using BIM to present good collaboration performances [3]. Collaboration performances make or mar project success. Considering the importance of collaboration in BIM project it is necessary to be able to effectively and accurately evaluate it. Indeed there is no good performance and improvement possible without a measure and monitoring of current performances.

A collaborative team needs performances assessment and continuous improvement to remain effective [4]. The evaluation of collaboration performances of project teams using BIM is necessary to analyse and determine current practices, their limits as well as changes required.

So far, many researches have highlighted that collaboration among participants is a necessity in BIM projects. Many other researchers have developed the importance of BIM performances assessment [7] without focusing on collaboration performances. Some researchers have investigated on requirements for collaboration in BIM [5] and some others have investigated collaboration within project using Integrated Project Delivery [15] but without considerations for BIM. Moreover they tend to examine collaboration outcomes rather than collaboration performances during the project. A proactive assessment is useful to make sure the project is meeting its requirements, from a collaboration point of view, and can help to understand what actions can be taken to improve the process. The main objective of this research is helping to fill this gap by providing a better understanding of current methods and developing a framework to establish metrics to evaluate collaboration performances in BIM projects.

II. Literature Review

A. *BIM Assessment Methods*

Many frameworks have been developed to measure BIM performances, most of them using the concept of maturity levels [7] but they differ by many aspects. Some of them are more user-friendly, easy to use while others are difficult to use and take time to be implemented. They also differ by their focus: some consider software, others process or organization. Their scopes are also very different, from project level to company size. The first of them to be developed is the Capability Maturity Model of the National Institute of Building Sciences, further developed into the Interactive Capability Maturity Model (ICMM). It uses eleven categories evaluated by ten Maturity Levels. The

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evaluation relies on subjectivity, there are no quantitative metrics to assess performances. More BIM Assessment Methods [7-9] have been developed through the years while researches established the limitation of previous methods. They evolved from evaluating approximatively one aspect of BIM to the assessment of more aspects (people, business process, technology), or focusing on one aspect (especially technology) with a better accuracy.

However these methods remain limited to assess collaboration performances. As established by Azzouz et al., current BIM Assessment Methods have several limitations [7] such as inaccessibility, lack of documentation and subjectivity. For example bimSCORE, the VICO BIM Score, or BIMe are not accessible in terms of development documentation or full public access. Others such as the CPIx BIM Assessment Form or BIM Proficiency Matrix don't come with a steady documentation, making them hard to use and analyse. Finally most of them rely mostly on qualitative parameters, assessed by BIM users or an audit. Therefore existing BIM Assessment Methods have a problem of subjectivity. As explained by Nicoletti and Prior (2006), subjective measures rely on personal judgement and are therefore influenced by individuals performing the measure whereas objective measures, quantitative, are more exact. Only few methods integrate quantitative measures, and only with many other qualitative factors. We can mention the VDC Scorecard, which integrates several metrics such as the number of Request For Information. The Characterization Framework developed by J. Gao [7] uses also several quantitative factors, and the BIM Cloud Score [9] as well. Quantitative factors used are for example the time spent on creating model, the number of stakeholders involve in creating and reviewing.

Beyond subjectivity of these methods, another problem is the limited consideration given to the evaluation of collaboration performances. The ICMM doesn't explicitly mention it, although it provides criteria that are related to it like Business Process. The BIM Proficiency Matrix developed by Indiana University suffers from the same problem and doesn't give any criteria related to collaboration. In his BIM Software Evaluation Model for General Contractor, J.M. Ruiz [8] mentioned the "Ability to Automated Setup, management and coordination" and the "integration with team collaboration software" as evaluation criteria, but it doesn't provide any deeper insight. The BIM Maturity Matrix define "Modelling-based collaboration" as the second of three BIM Capability Stages with five levels from initial to optimized. These Capability Stages and their level gives a description of different stages of collaboration within an organization using BIM but it doesn't provide easy to use factors or definition to assess these stages. Thus it is difficult to use it as an evaluation of collaboration performances. The BIM Quickscan uses a list of KPIs to assess BIM performances and turn around the concept of collaboration with KPI such as *organizational culture* or *data structure and information flow* but it is not intended as an actual evaluation of collaboration. In the CPIx BIM Assessment Form, collaboration is only mentioned through some questions such as "How do you collaborate?", but there is no evaluation factors provided. Moreover the CPIx use both the concept of "coordinate" and "collaborate", which are very similar, but the difference is not explained. It makes the assessment method even more confusing and not suitable for the evaluation of collaboration performances. The confusion between collaboration, coordination or even cooperation can be found in many BIM Assessment Methods. In his characterization framework, J. Gao refers more to coordination than collaboration in the measures he proposes. *Timing of coordination, duration of coordination, quality of coordination* are some measures he identified through his research, but their definitions, and how to use them to evaluate collaboration, or coordination performances is not specified. The preference for the term coordination rather than collaboration is also visible in the VDC Scorecard. It uses, among many qualitative and quantifiable metrics, the *number of inconsistencies* as a measure of "drawing coordination consistency" within "improve project quality objectives" and "improve project quality assessment". Lastly the BIM Cloud Score provides several quantifiable metrics but none of them are specified as benchmarking collaboration performances or coordination performances. Cloud services (Gteam, BIM 360 and others) are expected to be the future collaborative environment. However it is still in an experimental stage due to low system administration support, a complex user interface, and installation prerequisites [5].

Finally existing BIM assessment methods suffers from many problems to evaluate collaboration performances of project team using BIM in design phase. The problems scope from the lack of readability of the methods to the absence of quantifiable factors and the poor explicit consideration given to collaboration.

Figure 1 provides a brief history of some BIM-AMs. It is noticeable that the use of quantifiable metrics has been increased with the development of new BIM-AMs. It becomes more acknowledged that this kind of metrics are necessary and more reliable to effectively assess performances. One of the last of BIM-AM, the BIM Cloud Score developed by Du et al. [9] for benchmarking purpose relies only on objective, quantifiable, inherent, generic and representative metrics. On the other side, this method doesn't focus on the evaluation of collaboration performances.

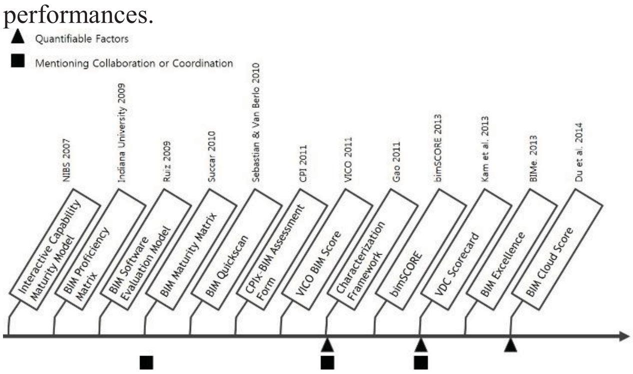

Figure 1 - History of BIM-AMs

B. BIM Collaboration Requirements

Beside BIM-AMs, researchers worked on requirements for collaboration with or in BIM. The requirements developed through these researches are essential function for BIM collaboration platform, or even Critical Success Factors (CSFs) for BIM implementation for collaboration [5][6][8]. These requirements and CSFs help to understand the relationship between BIM and collaboration. In their study of BIM collaboration requirements Shafiq et al. [5] identified four categories of features: model content management, model content creation, viewing and reporting, and system administration. While we take a look at some of the multiple features identified we can understand how collaboration work through BIM. Model content management requires "multiple data model formats", "model merging", "clash detection" and "conflict resolution", among other features. This means that collaboration in BIM involves uploading, gathering data of different natures and evaluating (with clash detection) them. Similarly, the discussion around models is a key factor, as identified through features such as "model comparison", "mark-up", "collaborative communication", and "report generation". Similarly the control of user interactions with the model, which means the definition and planning of roles and tasks, is reported as critical though features like "user profiling", "access control". The objective of this research is not to compare every features for BIM collaboration systems identified in the literature. These researches don't provide quantifiable metrics explicitly used to measure collaboration performances in a BIM environment. However it is worthy to note that such researches give some hints to understand the relationship between BIM and collaboration performances.

C. Understanding Collaboration and Collaborative Design

Through the analysis of existing methods to evaluate BIM performances, whether with BIM-AMs or BIM Requirements it has been appearing that these methods fail to provide effective tools to measure collaboration performances. Moreover it appears that there are more than one term coexisting in the literature. Sometimes the authors use the term of collaboration, sometimes coordination or even cooperation. In addition they rarely explain the reason that conducted them to privilege a term on another. This led the present author to consider the importance of defining and make clear the concept of collaboration, first step to be able to identify metrics to measure collaboration performances.

Firstly it is important to clean the confusion around communication, cooperation, coordination and collaboration. Why do individuals working on the same project say sometimes say they are *coordinating* ? Is a crew of a ship guiding it into port *collaborating* with the pilot who has come on board as it enters the harbor? Or are they *co-operating*? [11] Why the many thousands employees of a big company call themselves *collaborators*? In the literature few researchers have focused on the definition of these concepts. A noteworthy work is the study conducted by Mattessich and Monsey [12]. They have made clearer the difference between collaboration, cooperation and coordination. **Cooperation** is characterized by *informal* relationships that exist without a commonly defined mission, structure or effort. *Information is shared as needed. Authority is retained* by each organization. **Coordination** is characterized by more *formal* relationships and understanding of compatible missions. Some planning and division of roles are required. *Communication channels are established. Authority rests* in each organization. **Collaboration** brings previously separated organizations into a *formal and new structure* with full commitment to a common mission. It requires comprehensive planning and *well defined communication channels* at many levels. Authority is determined by the collaborative structure. These three terms can be understood as different levels of the same concept. Collaboration is the stage involving the most trust, commitment and risks.

Although understanding the relationship between these three terms helps to make clear the confusion existing in the literature about BIM performances and BIM collaboration, it doesn't provide a strict definition of collaboration. Jassawalla and Sashittal [13] defined collaboration as the coming of diverse interests and people to achieve a common purpose via interactions, information sharing and coordination of activities. For T. Kvan [11], collaboration is working with others with shared goals for which the team attempt to find solutions that are satisfying to all concerned. And Moor et al. [20] determined three characteristics of collaboration: real time sharing of data, aligned people and organizations, aligned processes and practices. These definitions of collaboration highlights the notions of interaction, sharing of information and planned activities behind the term collaboration. The definition of collaboration given by the Oxford English Dictionary is: the action of working with someone to produce something. The word come from the French *collaboration*, derived from the Low Latin *collaborare*, "work together to make earnings". From the definition of the dictionary to the ones found in the literature it appears that collaboration is the moment when two or more individuals come with a common goal and work to achieve it by a way they wouldn't have by working alone. There is therefore the notion of planning and exchanging information.

This research focuses on the design phase of a construction project, on a project team using BIM technologies. It is necessary to cross the now established understanding of collaboration on the design phase of a project, in other words, what collaborative design would be. It has been established by previous researchers that design is a sequence of discrete activities [11][14] and that collaborative design is probably sequential and cyclical. Team members may work together for moments then split to pursue individual activities, and thereafter regroup. This understanding match well the concepts of planning, sharing information, evaluating identified above as taking part in collaboration. Following that a model of collaboration in design phase has been developed in Figure 2.

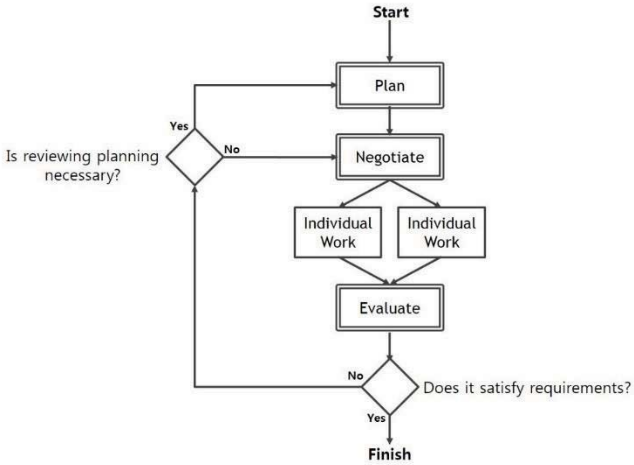

Figure 2 Model of collaboration in design phase.

This model adapted from previous researches [11] may be used to define a "collaboration cycle" as a "collaboration unit". It provides a framework which constitute a base for a better understanding of what a quantifiable metric for collaboration performances would be. The period during which people actually perform work individually can be a good indicator. It has been used in the literature [14] to analyse design process, without being linked to collaboration performances. However the best meaning remains unknown. What would it be? It could be the shorter it is the more partners collaborate. But it could also mean that the expertise of the individual is not good or that the negotiation phase wasn't done properly. Similarly the number of time the team talks about the design, for negotiation or evaluation could be a metric. The number of time clash detection occurs, which is an evaluation process inherent to BIM, may also be considered. These are some examples and it doesn't aim to be an exhaustive list of the possibilities. Moreover it is necessary to determine how these metrics should be understood.

III. Techniques and Metrics from the Literature

Some of the BIM-AMs use quantifiable metrics in their models. These metrics may sometimes be understood as outcomes of BIM collaboration in design phase, such as the number of rework [15], while others can fit, at least partially, the "collaboration unit" defined above such as the number of clash detection or the number of design alternatives performed. Determining which one or which combination of metrics have the best potential, is conducted in further researches. To understand better what kind of metrics are candidates, this section aims to provide a preview of some metrics that can be found in the literature, besides those that can be found in existing BIM performances evaluations. BIM involves deep changes in the construction industry and the processes engaged in design phase. Therefore classical performances indicators in areas such as costs, time or quality are probably not enough. Moreover they are collaboration outcomes indicators. Therefore it might be necessary to scope larger than only the literature related to construction.

Excluding BIM-AMs, several metrics can be found in the construction-related literature. Adirad and Pishdad-Bozorgi gathered a number of metrics to assess collaboration in IPD projects [15]. They categorized these metrics relatively to nine traits of collaboration within IPD (Co-location, multidisciplinary work, team productivity, costs impact, training, immediate feedback, real time sharing of data, methods of communication, degree of interaction, individual human aspect). Some metrics can be noticed as related to the framework of collaboration in design developed above. The *number of baseline revisions*, the *number of scope changes approved*, *denied and pending*, *number of change orders initiated by each different source*, *number of resubmittals*, *and number of RFIs* are all metrics than can rule the evaluation, plan or negotiation step of the collaboration cycle. *Average change order processing time*, *RFI processing time measured in weeks* and *lost time accounting (wait for information)* are all metrics related to the length of a collaboration cycle (at a different scale than individuals). *Frequency of interaction types (planned vs. unplanned)*), *how much time is spent collaborating*, *how often various modes of communication are used to collaborate (e.g. face to face or virtual)* can be mentioned too [15]. While developing and testing the Design Process Communication Methodology, Senescu and Haymaker[16] developed various metrics useful to measure the efficiency and effectiveness of collaboration. Therefore *frequency of value-adding information transfer between designe*r and the *number of positive design iterations* (the positive of use of design information produced by a designer by another designer) are two indicators of burden. The ability of a team to collaborate around a process can be measured by the *number of statements about design trends* (and the *number of positive design iterations*). The efficiency of collaboration around a process can be measured by the *number of complete and accurate design option produced.* Effectiveness can be measured by *internal information consistency* (a *high percentage of inconsistent information* can occur because team members share information with non-interoperable format). These inconsistencies can cause statement of confusion so collaboration effectiveness can also be assessed by the *number of statements of confusion*. Finally the *number of redundant tools*, and the *number of non-interoperable tools* can enlighten the collaboration process effectiveness and efficiency.

Another technique used in the literature is the Social Network Analysis. Social Network Analysis (SNA) has been widely use to analyse organizations, relationships and communications within organizations. However it relies a lot on how the Social Network is build, which means how interactions between individual are counted. What should be considered: the number of time agents interact, the period between two interactions or the amount of data they exchanged? The proper way to build such a network for assessing collaboration remains largely unknown and need to be assessed in further researches. The following factors of networks have been used by researchers [18][19] to characterize coordination or communication in an organization. *Density* indicates the amount of interaction between individuals. The larger the density, the greater the volume of communication in the network. *Centrality* reveals the distribution of relationship through the network. In a high centralized network, a small percentage of its member will have a high percentage of relationship with its other members. *Betweenness* measures the amount of information that passes through an individual and can reveal bottlenecks. *Geodesic distance* indicates either the distance between two nodes with the greatest separation or the distance between two separated nodes. Large distance between nodes may reveal difficulties in their exchange of information. *Average shortest path*: networks with low shortest path values tend to transmit information more accurately and timely thus leading to better overall communication. *Modularity* measures the strength of division of a network into modules. Network with high modularity have dense connections between the nodes within modules but sparse connections between nodes in different modules.

After collecting the different metrics from the literature it is possible to determine which the best candidates to evaluate collaboration performances and to determine their relevant interpretation. Finally some metrics should be interpreted quantitatively and qualitatively, in order to reflect the intangible status of collaboration [15].

IV. Discussions and Conclusion

The development and implementation of BIM is one of the most significant transformation operated by the AEC industry. In a project using BIM, success depends on collaboration of team members. Therefore developing and maintaining the collaboration is a necessity and requires continuous performances assessment (Adirad and Pishdad-Bozorgi 2014). The analysis of existing researches of BIM performances assessment show that these methods largely fail to provide usable, understandable and reliable (non-subjective) metrics. Moreover proactive evaluation of collaboration performances remains largely ignored by these methods (Figure 1). Consequently this paper propose a framework to understand collaboration in design phase, first step of a proper development of metrics for the evaluation of BIM collaboration performances in design phase. Based on existing researches, it makes clear the meaning of collaboration and the different stages and steps in design collaboration (Figure 2). Finally it provides a wide analysis on the existing metrics related to collaboration performances that can be found in the literature. Therefore it suggest a methodology to develop the metrics that could be suitable for a usable, understandable and reliable proactive evaluation collaboration performances in BIM project. The first two steps of this methodology are exposed in this paper: developing a strong model of design collaboration and reporting potential candidates for the metrics already developed in the literature. The third step would be to select the metrics, their combination and enlighten their interpretations. The fourth step would be integrating them in a larger framework including the evaluation of People/Organization, Technology and Process. This third and fourth steps are being conducted in further researches.

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