Towards a Framework to Understand Multidisciplinarity in BIM Context - Education to Teamwork

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Abstract

Construction projects by their very nature, have always involved the cooperation of various disciplines. Typically, construction projects are unique and large, comprising of many phases, requiring major investment and activities that are spread amongst multiple disciplines. Active collaboration and effective teamwork between project participants is thus considered central and critical. Multidisciplinarity in construction projects however requires careful investigation of team selection that is based upon individual skills and competences. The industry today is inclining towards the adaptive use of model-based processes and technologies namely building information modelling (BIM), and there is a need of BIM competent workforce to support these ongoing changes. Study of the impact what different levels of BIM skills and competences an individual has in multidisciplinary team selection and how the multidisciplinarity of the BIM team works is a relatively new area of interest for researchers in academia and industry alike. This paper thus proposes a conceptual framework for assessing multidisciplinarity in BIM context.

Keywords: Add up to five keywords here, separated by commas

1. Introduction

Construction projects are unique by nature and include a wide variety of disciplines, individuals and organizations working towards a common goal. Traditional methods of construction project planning, designing and execution have been fragmented across multiple firms and disciplines. Effective and efficient collaboration amongst the project participants is seen as critical and beneficial for projects, leading to greater efficiency, quality, and hence, increased productivity for the construction industry as a whole. Today, we see different methods, processes and technologies being actively implemented to support collaborative ways of working, such as building information modelling (BIM).

BIM is considered a disruptive technology that provides a new way of managing the design and construction of projects with wide support for collaboration (Eastman et al., 2008; Gu et al., 2008; Hardin, 2009; Arayici, Egbu, & Coates, 2012, Yalcinkaya & Singh, 2015). BIM processes and technologies are increasingly being implemented at varying levels across the world. There is currently a rapid growth in BIM adoption and implementations in construction projects of different scales and nature. According to the literature, there has been 21% increase in BIM adoption from 2007 to 2009 in North America (McGraw Hill, 2009); 12% increase from 2009 to 2010 in Europe (McGraw Hill, 2010); 41% increase from 2010 to 2014 in UK (NBS, 2015).

One of the basic constituents of successful BIM implementation is efficient collaboration amongst project participants and the multidisciplinarity of the team involved. While multidisciplinary teams are considered important, there has been very little conceptual and methodological support (1) to objectively assess and compare multidisciplinarity of two or more individuals or teams, (2) to measure the impact of individual expertise on multidisciplinary teams, and (3) to define which of the many combinations of multidisciplinary skills is suited to a given context. Thus this paper aims to present a conceptual framework that could be further developed to understand multidisciplinarity in BIM context.

2. Background

2.1 Multidisciplinarity approach

Creating teams made up of varying disciplines, in general, facilitates the resolution of complex problems by generating new and creative solutions. The Oxford dictionary defines the term “multidisciplinary” as “combining or involving several academic disciplines or professional specializations in an approach to a topic or problem.” Various sources in literature identify the importance of multidisciplinarity in teamwork. Choi & Pak (2006) define the objective of multidisciplinary approach as “to resolve real world or complex problems (...and) to provide different perspectives on problems”. Similarly, Cross (2004) highlights the importance of multidisciplinarity as an approach to increase the possible generation of creative solutions through interconnection of interdisciplinary knowledge of participants.

Multidisciplinary teams, on one hand are required and beneficial for solving critically important and complex problems, while on other hand can also provide new dimensions towards innovative knowledge generation and creation. Individual expertise, skills and competencies have direct impact on dynamics of multidisciplinarity in teamwork and so a balanced synthesis amongst required fields is important for effective multidisciplinary team building. Given the complexity of social, technical and process variables when working as part of a team in a construction project, it is important to gain an understanding of what multidisciplinarity means in the specific context of AEC industry. This understanding is particularly necessary given the traditionally silo mentality that exists between the engineering disciplines.

2.2 Multidisciplinarity in construction projects

Construction projects by their very nature, have always involved the cooperation of various disciplines. Typically, construction projects are unique and large, comprising of many phases and requiring major investment. Output of a construction project is a collective effort and goal of multiple disciplines involved. Due to the fragmented nature of activities, active collaboration and teamwork is being considered as essential today in construction projects.

A significant factor accounting for the fragmentation of the AEC industry is organizational divisions due to the fact that the industry is made up almost entirely of SMEs (small to medium enterprises) many of these acting in a single discipline. The annual report on SMEs by the European Commission concluded that between 2012 and 2013, 90 % of total people employed in the European construction sector work in SMEs and furthermore SMEs contributed €400 billion to the construction sector out of the €485 billion total value added production (Gagliardi et al., 2013). Given that such a large percentage of the industry is made up of small to medium organizations, many of which are mono-disciplinary, it becomes imperative that exchange of information and skills between organizations be explored in greater depth to gain an understanding of multidisciplinarity.

Various tools, processes and technologies have been developed and implemented to facilitate, support and enhance multidisciplinary collaboration. Contractual models such as PPP (Private Public Partnerships), IPD (Integrated Project Delivery), Alliance contracts and partnering encourage shared interest in project success by giving the participants a vested interest/ownership. Further to the development of integrated contractual arrangements to encourage multidisciplinary collaboration and partnering, various tools and methods have been developed to improve the capabilities of the organizations involved. Building Information Modelling (BIM), BIG room (BR) and Knotworking (KW) are amongst a number of which have been developed to facilitate collaboration in multidisciplinary projects. However, all these approaches are enablers to create multi-disciplinary environments, but they by themselves do not provide any decision support on how to compose a balanced multi-disciplinary team.

2.3 BIM and multidisciplinarity

BIM is widely accepted as a revolutionary technology, and potentially revolutionary socio-technical approach for collaboration in construction projects. BIM adoption, implementations and its benefits for construction projects has been widely discussed and researched. Active collaboration between the project participants and smooth data exchange between the tools they utilize is considered a key to successful BIM implementation. Thus, adaptive use of BIM not only requires but also supports multidisciplinarity.

2.3.1 How BIM influences/ supports multidisciplinarity

BIM support multidisciplinarity at individual as well as team level. Some of the aspects of BIM supporting multidisciplinarity are listed as follows:

- **BIM and multidisciplinary communication -** Koutsikouri et al., (2006) state that "success in a multidisciplinary practice depends on (...) the quality of interactions between team members". Recognizing that a BIM approach facilitates better quality interactions between team members it surmises that BIM adoption is ultimately positive as a multidisciplinary team.
- **3D coordination -** The majority of interest and focus (with regard to BIM approach) is in the area of 3D coordination. According to Jung and Lee (2015) 85% of AEC companies surveyed considered this to be the most important utilization of BIM today.
- **Common data environment** - Single file concept of integrated BIM for multidisciplinary data exchange.
- **BIM as a knowledge creation and exchange platform** - integrated domain specific knowledge.
- **BIM as a tool for multidisciplinarity input -** BIM applications as knowledge-based systems have a lot of integrated interdisciplinary and organizational knowledge. An architect with limited experience in energy modeling can still run preliminary energy simulations to know how his/her design is performing with regard to energy.
- **Design authoring -** Integrated teamwork possibilities within domain specific BIM environments for informed decision making.

2.3.2 How BIM requires multidisciplinarity

As discussed earlier, BIM technologies, their adoption and implementation requires collaborative teamwork and processes. Development of new roles and need of new competencies for disciplines suggest new approaches and requirements for multidisciplinary collaboration amongst the project participants. As an example, the job of BIM coordinator/BIM manager has become a common role only in the past approx. 5-10 years to support coordination and management of multidisciplinary team and activities spread among different disciplines.

Therefore, BIM requires multidisciplinary skills and knowledge both at individual and team level.

- Individuals not only need to know about their own discipline but also need to have BIM skills and knowledge. i.e. domain knowledge as well as BIM knowledge; and
- The team as a whole not only needs to know about the domain areas, but also needs to know how to work together and collaborate in a BIM project, i.e. task knowledge as well as teamwork knowledge, including teamwork in the context of BIM.

Therefore, it is desirable to understand the balance of domain vs BIM knowledge that is required at individual levels, and similarly, what is the balance of task vs team knowledge needed at team level. Currently, there are no methodological approaches to assess or understand these requirements.

2.4 Need for a common framework for multidisciplinarity assessment

With increase in BIM adoption and implementations, the need of multidisciplinarity in teams has been highlighted as a core element in BIM based projects. There is a need for processes and methods to assess multidisciplinarity both at individual and team level, for smooth BIM transition and to support the technological changes brought about by BIM. We furthermore highlight the need of a common framework for multidisciplinarity assessment for the following reasons at individual level and team level:

2.4.1 Individual level:

There is lack of BIM capability assessment criteria, standards or standardized accreditation. As diverse BIM tools and technologies are present, there is not yet any common system for assessing individual BIM competencies and guidelines to support the level of BIM expertise needed. There is much variance in individual BIM competences dependent upon level of BIM knowledge, BIM skills and the level of expertise required for a project of differing types. Assessment of individual BIM tool competences can be seen emerging for specific BIM applications conducted primarily by private industry such as software vendors. These individual level of competences are important, however, requirements vary according to the project type, location and diversity of BIM tool utilization. No system defining these levels or competences has yet been developed.

2.4.2 Team level:

The level of BIM application competences in accordance with the level of domain expertise have several possible combinations and thus have direct impact on the level of team competence and multidisciplinarity in teams. Not only is the individual BIM competence assessment (individual BIM competent profile) missing, a system for selecting a BIM competent team based on the skills required for a project, does not exist (Multidisciplinary team profile).

We see that a common framework for understanding multidisciplinarity at individual and team level would be able to assist in the composition of multidisciplinary project teams. It is the view of the authors that developing a common framework to measure and compare multidisciplinarity levels in the AEC industry both at individual and team level could provide a tool, method and system for team selection. The core concept of development towards a framework to understand multidisciplinarity in BIM context is thus discussed and presented. Furthermore, we see an opportunity for utilizing the framework for various purposes and needs in different fields such as recruiting and employment (comparison of candidates), development of BIM educational activities and programs (aligned to industry requirements of graduates) as well as to facilitate team selection criteria for BIM based projects.

3. Conceptual outline for the multidisciplinarity framework

Different maturity matrix models have been developed over time that claim to precisely quantify BIM maturities of people (individual and team level), processes (organizational level) and product (project level). Amongst the present BIM maturity toolsets, organizational and project level maturity are much more focused; whereas only “BIMe” is present for assessing individual as well as team maturity as shown in Figure 1.

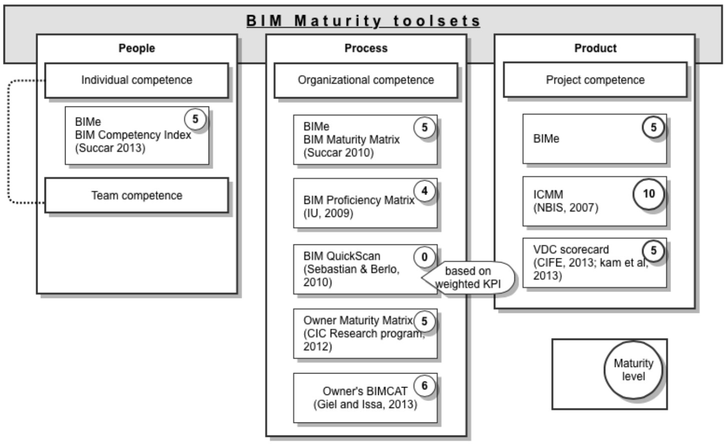

Figure 1: BIM maturity tool comparison (adopted from Geil and McCuen, 2014)

Our conceptual focus goes beyond assessing the maturity levels to understanding the BIM competence combinations and the varying level of combination possibilities that would help in optimizing multidisciplinary team formation and see its impact on the possible team compositions. Thus, rather than focusing only on assessing a team’s maturity, we also intend to develop methodologies of profiling so that we can understand the desirable composition. That is, out of the numerous permutations and combinations possible for skills and expertise levels, which combinations are desirable and suitable to a specific context is needed, Figure 2.

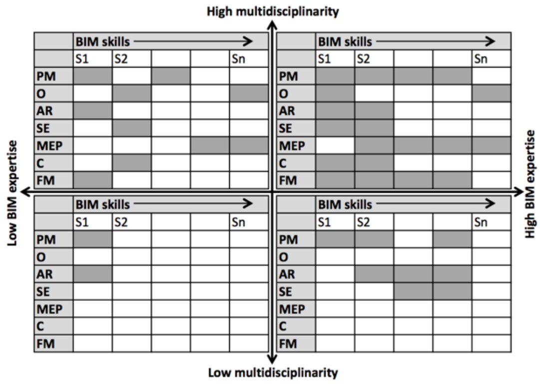

Figure 2: Individual and team profiles as a combination of disciplines and expertise levels aligned with BIM skills (Adopted from Singh and Casakin 2015)

As an analogy, you do not get the best football team by putting together a team of all the best players in different positions. A good team has a balance of top class players, good players and promising rookies, who can still collaborate to potentially give the best result. How do we achieve the same level of team management in BIM projects? How do we profile the team members and team for their various competences, and identify areas for improvement at both the individual and team levels?

3.1 Individual profile - Individual BIM competent discipline

Project participants today require adequate BIM knowledge and skills of tools and processes along with the discipline specific knowledge and processes. We term the disciplines as "individual BIM competent discipline" (in generalized form "Dn"). This integrated BIM competent discipline profile has different variances (D1a, D1b,...D1n as represented in Figure 3) depending upon the level of expertise and knowledge an individual has both in their own disciplinary field as well as with BIM.

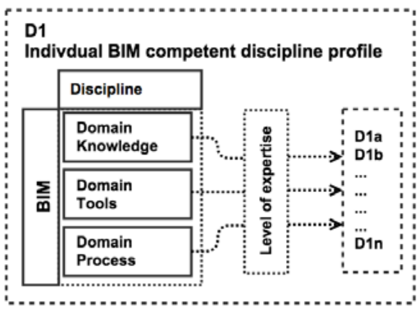

Figure. 3 – Individual BIM competent discipline profile formation

As the use of BIM varies with project type and scope, primary and secondary BIM uses from Kreider et al (2010) (Appendix 1)has been followed and defined as the 25 BIM skill set in this paper. Common BIM requirements (CoBIM, 2012) series has been extensively followed in this paper to develop the project participants and the roles needed for a BIM project. The identified roles and responsibilities in a typical BIM project are listed as seven disciplines, namely - project manager (PM), owner (O), Architect (AR), Structural engineer (SE), Mechanical electrical and plumbing engineer (MEP), Contractor (C) and Facility manager (FM). We are aware of emerging new roles of BIM coordinator/manager (Lehtinen, 2010), however for this study we include it as a role conducted by a project manager.

Different maturity matrices use a range of 4-10 maturity level as presented in Figure 1. To make it simple at this conceptual stage, we follow the approach of Succar & Kassem (2015) and adopt five level of maturity levels represented as level 1: low, level 2: medium-low, level 3: medium, level 4: medium-high, and level 5: high. A baseline standard thus could be easily adopted in an individual, organizational as well as national level to support and define the minimum BIM competence required. For example, if a standard baseline of a PM is set as of minimum requirement of level 4, presented scenario in Figure 4, would have a direct approach for the preferable PM with level 4 competence.

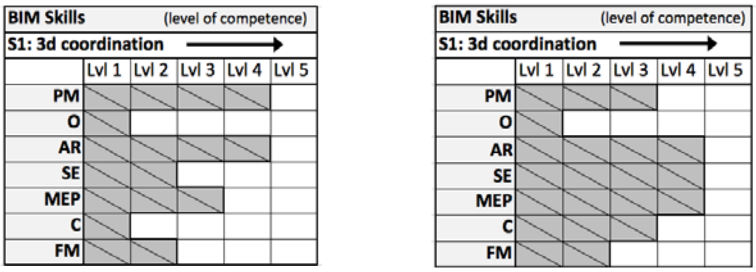

Figure 4 - Possible individual BIM skill profile depicting a possible multidisciplinary team composition for 3d coordination skill

3.2 Multidisciplinarity and BIM expertise - Team profile

The variance of individual BIM competent discipline profile provides the possibilities of generating different combinations of multidisciplinary teams. The teams thus generated could be compared with benchmarked profile of a multidisciplinary team to depict the best possible solution based on the project as presented in Figure 5.

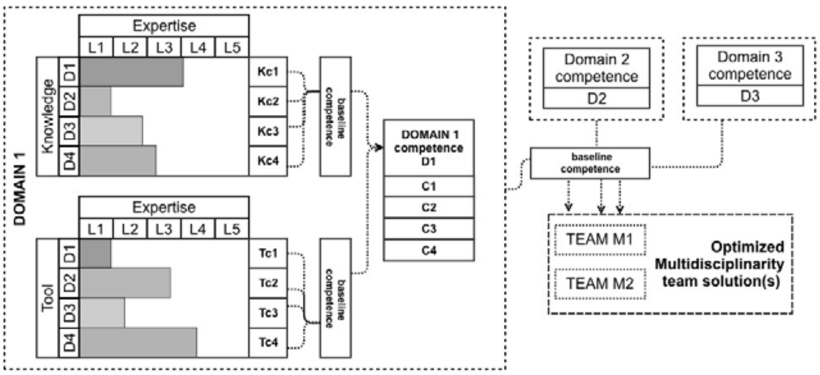

Figure 5: Optimized multidisciplinary team solutions

Thus, the possible combinations of multidisciplinarity and levels of BIM expertise is large and so there is very rare evidence about how the multidisciplinarity of team and individual BIM competences influence the team performance.

4. Future work / Discussion

The authors in near future aim to implement the presented conceptual framework for various scenarios ranging from education to teamwork in AEC projects that will help in validating and giving more rigorous results in practical scenarios. BIM skills identified will be filtered for the various planned case projects and thus applied to validate its usefulness.

4.1 Mapping individual skills and profiles

Multiple approaches to creating and validating the multidisciplinary assessment framework will be applied. Building on the existing research and industry surveys conducted in various parts of the world (e.g. McGraw Hill, 2009, 2010; Kreider et al., 2010; Finne et al., 2013; NBS 2015), this research will collect further data within classroom settings, offices and recruitment agencies. The questionnaires for collecting data will begin with an open ended structure, where respondents will be asked to identify the skills they deem most important for their role. In the next phase, a list of skills will be given for respondents to choose from and rank in order of their importance. In the final phase, for each of the shortlisted skills ranked high by the participants, they will be required to use a Likert scale (varying level of scales will be implemented based upon the case projects) to mark the level of expertise desirable in that skill set. Thus, the questionnaire will create a matrix of the number of skills and the level of expertise in each of the skill sets. In addition, experimental set-ups with simulated BIM projects will be used to test the applicability of the framework.

4.2 Validate the mapping of skills and profiles

In order to validate the proposed conceptual framework, future work may test the framework in a multidisciplinary setting, observing skills as they are acquired and measuring the effects on the profile of the group and, of course, its performance at the given task. Therefore, the authors will implement it in a workshop bringing together design students from various backgrounds to simulate a BIM based construction project scenario. The students will simulate their roles resembling a real construction project. The workshop has been planned as a small structure that should, for its completion, bring together a number of trades and construction methods. The team will utilize BIM for the design and construction of the structure. In order to simulate roles more accurately, BIM dimensions focused includes digital project controlling in order to track and analyze progress of the construction activities and phases.

Based on the conceptual framework presented, Figure 6 shows the baseline for required project participants and the BIM skills focusing the planned construction workshop. The framework suits the type of project and group of disciplines. The BIM competences are rated out in Likert scale of range 1-5 to generate the baseline profile for the team.

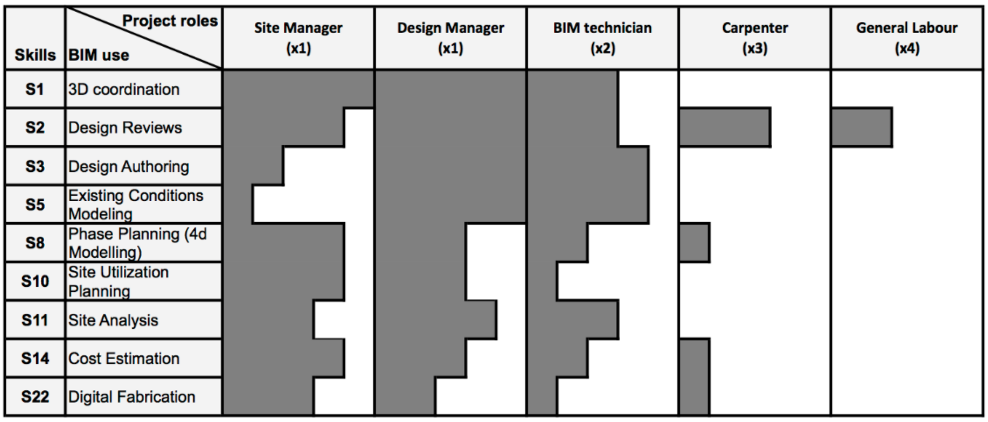

Figure 6 - BIM skills required of workshop participants

As a method of benchmarking, the framework prepared is planned to be distributed within industry as questionnaires for further validation of the BIM competences specific to Finnish requirements. Respondents would be instructed to fill out the framework with the desired range and level of BIM skills needed for the team and project. Having these industry requirements as a benchmark, the data collection will be aligned with the participants of the workshop. The participants during the workshop will fill in their skills into the framework at two levels - before the workshop to map expectations and understandings of the participants and after the commencement of the workshop to validate the usefulness of implementation. With the perceived usefulness of the implementation, authors seek to furthermore assess the impact in BIM learning. Furthermore, we hypothesize that these types of collaborative approaches of working in a multidisciplinary environment generates new skills and assist in learning from each other while simultaneously completing the project more effectively.

5. Conclusion

It is agreed in the literature that multidisciplinary collaboration in projects leads to the generation of creative solutions for complex problems. Global increase in BIM adoption and its diversified implementations have shown that BIM is here to stay and will be a de-facto attribute for the professionals. Various researches and industry implementations suggest that success of BIM based projects require integrated multidisciplinary team and active collaboration amongst the individuals. However, the level of BIM competencies and its impact on the multidisciplinary team formation and its effectiveness is still a very young research area. Authors believe that the framework presented will help in assessing BIM competences at individual as well as team level. It will furthermore guide towards development of systems and method to both assess and support on how to compose a balanced multi-disciplinary team.

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Appendix 1 - *BIM skills based upon BIM use frequency and benefit with respect to rank order from Kreider, et al., (2010)*

Skills	*BIM use*	*Description*	*Discipline*
S1	*3D coordination*	*A process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems.*	*PM, AR, SE, MEP, C*
S2	*Design Reviews*	*A process in which stakeholders view a 3D model and provide their feedbacks to validate multiple design aspects.*	*PM, AR, SE, MEP, C*
S3	*Design Authoring*	*A process in which 3D software is used to develop a Building Information Model based on criteria that is important to the translation of the building's design.*	*PM, AR, SE, MEP, C*
S4	*Construction System Design*	*A process in which 3D System Design Software is used to design and analyze the construction of a complex building system (e.g. form work, glazing, tie-backs, etc.) in order to increase planning.*	*PM, O, AR, SE, MEP, C*
S5	*Existing Conditions Modeling*	*A process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility.*	*PM, AR*
S6	*3D control and Planning*	*A process that utilizes an information model to layout facility assemblies or automate control of equipment's movement and location.*	*PM, C, FM*
S7	*Programming*	*A process in which a spatial program is used to efficiently and accurately assess design performance in regard to spatial requirements.*	*PM, O, AR*
S8	*Phase Planning (4d Modelling)*	*A process in which a 4D model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site.*	*PM, AR, SE, MEP, C*
S9	*Record Modelling*	*Record Modeling is the process used to depict an accurate representation of the physical conditions, environment, and assets of a facility. The record model should, at a minimum, contain information relating to the main architectural, structural, and MEP elements.*	*PM, FM*
S10	*Site Utilization Planning*	*A process in which BIM is used to graphically represent both permanent and temporary facilities on site during multiple phases of the construction process. It may also be linked with the construction activity schedule to convey space and sequencing requirements.*	*PM, AR, C*
S11	*Site Analysis*	*A process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project.*	*AR*
S12	*Structural Analysis*	*A process in which analytical modeling software utilizes the BIM design authoring model so to determine the behavior of*	*SE*

		a given structural system.	
S13	*Energy Analysis*	*The BIM Use of Facility Energy Analysis is a process in the facility design phase which one or more building energy simulation programs use a properly adjusted BIM model to conduct energy assessments for the current building design.*	*MEP*
S14	*Cost Estimation*	*A process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the lifecycle of a project.*	*AR, SE, MEP, C, FM*
S15	*Sustainability LEED Evaluation*	*A process in which a BIM project is evaluated based on LEED or other sustainable criteria.*	*AR, MEP*
S16	*Building Systems Analysis*	*A process that measures how a building's performance compares to the specified design. This includes how the mechanical system operates and how much energy a building uses.*	*MEP*
S17	*Space management/tracking*	*A process in which BIM is utilized to effectively distribute, manage, and track appropriate spaces and related resources within a facility.*	*PM, AR, FM*
S18	*Mechanical Analysis*	*A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications.*	*MEP*
S19	*Code Validation*	*A process in which code validation software is utilized to check the model parameters against project specific codes.*	*PM, AR*
S20	*Lighting Analysis*	*A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications.*	*MEP*
S21	*Other Engineering Analysis*	*A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications.*	*AR, SE, MEP*
S22	*Digital Fabrication*	*A process that uses digitized information to facilitate the fabrication of construction materials or assemblies. Some uses of digital fabrication can be seen in sheet metal fabrication, structural steel fabrication, pipe cutting, prototyping for design intent reviews etc.*	*AR, SE, C*
S23	*Asset Management*	*A process in which an organized management system is bi-directionally linked to a record model to efficiently aid in the maintenance and operation of a facility and its assets.*	*O, FM*
S24	*Building Maintenance Scheduling*	*A process in which the functionality of the building structure (walls, floors, roof, etc.) and equipment serving the building (mechanical, electrical, plumbing, etc.) are maintained over the operational life of a facility.*	*FM*
S25	*Disaster Planning*	*A process in which emergency responders would have access to critical building information in the form of a model and information system.*	*AR, FM*