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## **SCRUTINIZING SHARED MENTAL MODELS FOR INTER-ORGANIZATIONAL AEC PROJECT TEAMS: PROJECT DELIVERY METHODS PERSPECTIVE**

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# SCRUTINIZING SHARED MENTAL MODELS FOR INTER-ORGANIZATIONAL AEC PROJECT TEAMS: PROJECT DELIVERY METHODS PERSPECTIVE

## 1. Abstract

*The aim of this study is to develop a theoretical basis for utilizing shared mental models (SMMs) in inter-organizational AEC project teams. The concept of SMM is well established in the psychology of cognition, and proven to have an influence on team performance. Despite extensive research, the literature shows variant views regarding the SMM construct. Aiming to bring clarity to this area, a synthesis of the SMM literature is performed, and a new framework categorizing the SMM construct is proposed. As the previous studies do not address the use of SMMs according to the needs of Architecture, Engineering, and Construction (AEC) project teams, the SMM knowledge specific to AEC teams is defined, and discussed in relation with various project delivery attributes. The study contributes to the body of knowledge by proposing a new categorization for SMMs based on literature, and identifying various knowledge areas for SMMs in AEC project teams via consideration of project delivery methods.*

**Key words:** Shared Mental Models; Synthesis; AEC project teams

## 2. Introduction

In Architecture, Engineering, and Construction (AEC) literature, considerable amount of research exists, focusing on the impact of explicit coordination (i.e., coordination through communication) on team performance (Franz et al., 2016; Mollaoglu-Korkmaz et al. 2014; Khairil et al., 2013). Recently, the limitation of explicit coordination has been realized, and the importance of implicit coordination has been highlighted in the literature. Implicit coordination takes place when team members anticipate the needs of their teammates, and behave accordingly, without any communication or planning (Rico et al., 2008). Implicit coordination is a function of team cognition: where team members have similar structure of knowledge related to teams. The most well-known, well-developed, and holistic team cognition construct is Shared Mental Models (SMMs) (Mohammed & Dumville, 2001). SMMs refer to the knowledge and its uniform understanding, that team members share in an organized manner (Klimoski & Mohammed, 1994; Cannon-Bowers et al., 1993).

High quality SMMs have been empirically proven to improve team performance, as they enable team members to accurately predict their teammates' behaviors, and the team requirement. Various fields have adopted the concept, modified it for their application needs, and utilized to devise strategies for improving SMMs in teams. Unfortunately, the AEC literature, so far, lacks studies in this area. This deprives the industry from gaining the full benefits of implicit coordination. Thus, there is a need to explore SMMs in the context of AEC project teams considering their complex (project based, inter-disciplinary, and inter-organizational) nature.

This study aims to lay the groundwork for improved understanding of SMMs and their use for the AEC project teams. The objectives of this research are as follows: i) To perform a critical review of the SMM literature, and develop a framework categorizing its constructs, and ii) To examine the AEC project delivery attributes via the lens of this new SMM framework.

### 3. Background

#### 3.1. Shared Mental Models

The idea of SMMs was proposed by Cannon-Bowers et al. (1990) in an effort to better understand, and improve team performance and decision-making. Rouse et al. (1992) stated three functions of SMMs 1) Description; 2) Explanation; and 3) Prediction. Description allows the team members to comprehend the information in a similar manner. It answers questions regarding the reasons of existence and appearance. Explanation then delves into the details of procedures and results. Finally, prediction enables team members to anticipate the same outcomes and repercussions of specific actions. Figure 1 summarizes the nature of SMMs given by Rouse et al. (1992).

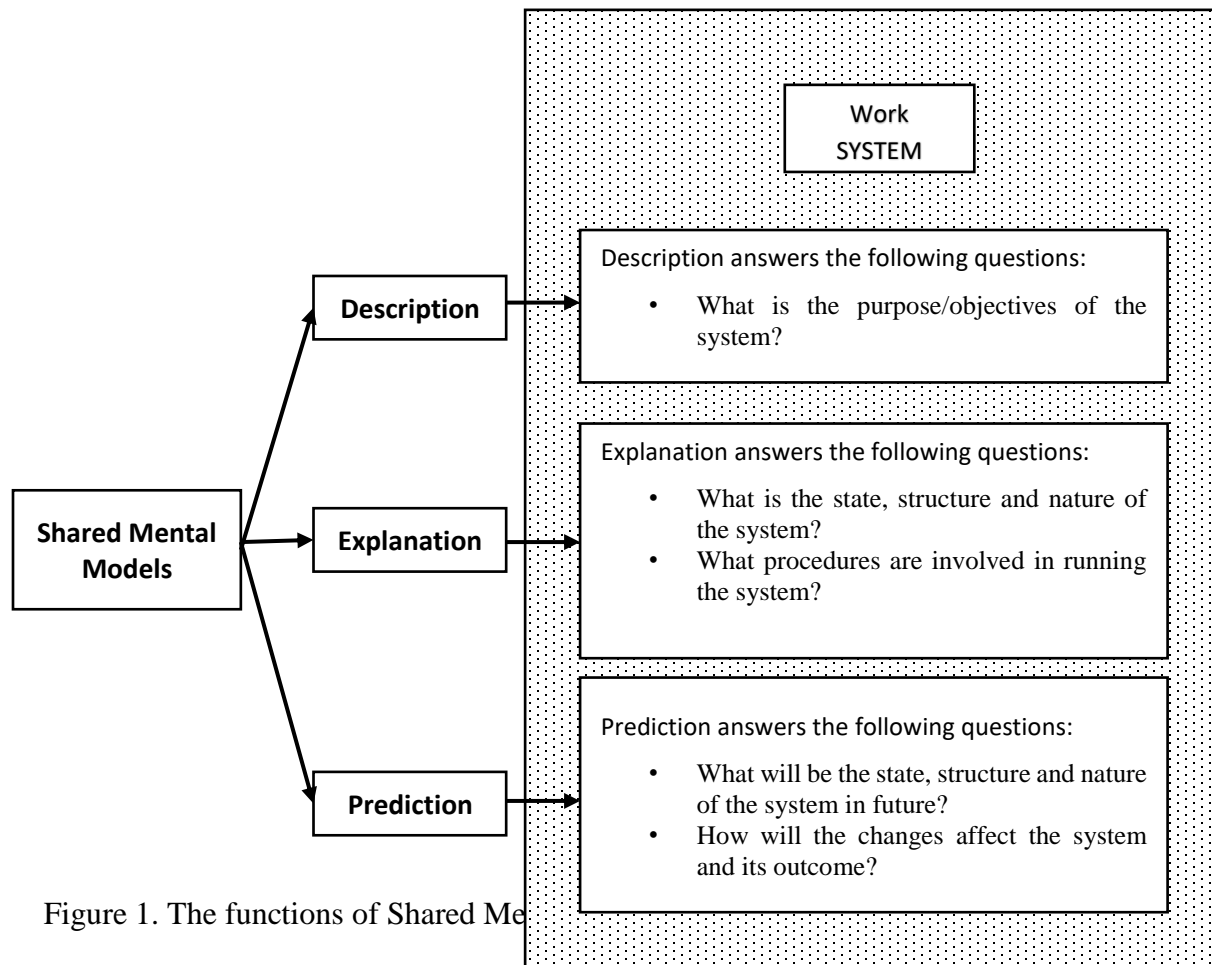


Figure 1. The functions of Shared Me

Extensive research has made SMM one of the most developed psychological concept related to cognition (Mohammed et. al., 2010). Since the very inception of the idea, it was hypothesized that SMMs contribute towards team performance (Rouse et. al., 1992, Cannon-Bowers et al., 1993 & Klimoski & Mohammed, 1994), and it followed a series of empirical evidence in the support of this claim (Stout et al., 1999; Mathieu et al., 2000; Waller et. al., 2004; Salas et. al., 2005; Edwards et. al., 2006; Santos et. al., 2015). The rationale given by Cannon-Bowers et. al. (1993) was that the teams perform more effectively when they share their understanding regarding the tasks, teams, equipment, rules, goals and other aspects. This helps the team members to predict the actions and

behaviors of other team members, which becomes very critical especially in the scenarios where time limits and other constraints disallow detailed communications and interactions (Mathieu et al., 2000). In addition to similarity of mental models amongst the team members, the accuracy of the models is also very important and often overlooked (Edwards et al, 2006). Mathieu et al. (2005) refer to it as the quality of mental models, which includes both accuracy and detail of information. Mental models not only provide us with the opportunity to understand performance, but also to enhance it. With an in-depth analysis of various components of mental models in teams, we can identify the loop holes in the communication methods, knowledge bases and other aspects. Thus, trainings and other remedial measures can be designed as a result of this exercise (Rouse et al., 1992).

Our literature review revealed limited number of studies measuring shared mental models directly in the field, for real teams in various industries. Laboratory setting based studies were excluded from our review, as they include small teams with specific tasks, and their results are not realistic enough representation of actual conditions (Lim & Klein, 2006). The resulting sample of studies were performed in the following fields: construction (Lingard et al., 2015), education (Johnson et al., 2011), engineering (Avnet & Weigel, 2013), information Systems (Hsu et al., 2011), military (Graham et al., 2004), plant control (Waller et al., 2004), software development (Lavesque et al., 2001), sports (Blickensderfer et al., 2010) and training (Smith-Jentsch et al., 2001). Table 1 lists these studies with the relevant details.

Table 1 Shared Mental Model Studies in the Literature

Field	Types of Teams	Aspects measured	References
Construction	Individuals	Judgement regarding accidental injuries associated with different systems	Lingard et al. (2015)
Education	Functional teams	Team related knowledge	Johnson et al. (2011)
Engineering	Cross-disciplinary teams	View about design drivers	Avnet & Weigel (2013)
Information Systems	Individuals	Teamwork mental models	Hsu et al. (2011)
Military	Cross-disciplinary teams	Estimates of other members' Workloads	Graham et al. (2004)

Power plant control	Functional teams	Understanding of the situation and response	Waller et al (2004)
Software development	Functional teams	Team issues	Levesque et al. (2001)
Sports	Pairs/functional teams	Shared Expectations	Blickensderfer et al. (2010)
Training	Individual	Teamwork mental models	Smith-Jentsch et al. (2001)

Although compelling, these studies are limited in their approach as they are restricted to only a few knowledge components, and do not aim for sub-group comparisons. Thus, the full potential of SMMs to identify the lacks and lags of shared knowledge, and subsequently enable to optimize the project performance, remains untapped. For example, the only SMM study in construction industry we found is by Lingard et al. (2015). They measured the similarity of a single SMM element (safety judgement) amongst different construction stakeholders. The sample included 15 architects, 15 engineers, 15 contractors, and 15 safety professionals. They were all put in the same pool, and measurement was done on a single sample. Furthermore, this sample did not belong to a single project, which made the findings even less contributory. There are similar, limited approach issues with other studies as well.

Thus, the literature lacks precedents of effective SMM application for AEC project teams, or similar complicated systems. The first step towards improving the research in this area would be to identify and define the SMM knowledge that can be shared amongst the AEC project teams.

### **3.2. Inter-Organizational AEC Project Teams and Project Delivery Methods**

With constantly changing needs of modern times, all industries are adopting projects as means of execution because of the flexibility they provide and the long-term commitments they avoid (Duysters & de Man, 2002). Inter-organizational projects involve two or more organizational actors from distinct organizations working jointly to create a tangible product/service in a limited period of time. They are very different from projects involving only a single organization like an organization's capacity building, development, or change projects. They are complicated in nature, and there are many actors from various organizations involved in coordinated and overlapping activities (Jones & Lichtenstein, 2008).

Inter-organizational AEC projects are very complex systems. They are location specific. There are a number of organizations and disciplines involved. The inter-disciplinary and inter-organizational relations are potentially adversarial in nature, due to the conflicting priorities of organizations and functions (Forbes & Ahmed, 2011). Also, due to the project based temporary nature, new teams are formulated for each project, and dissolved on the completion. This impedes the development of long term relations. Finally, there are many internal and external constraints involved - like

regulations, environment, socio-political conditions, and lack of finances - which add to the complexity

Project delivery method plays a key role in shaping the project teams, by defining the nature and extent of relationships (Alarcón & Mesa, 2014). The nature of project delivery in AEC teams has been evolving. Before the 20<sup>th</sup> century, there were experts known as the “master builders” who were hired by the owners whenever they needed to construct any facility. These master builders were responsible for the complete process, including the design and construction. However, in time design and construction became more diverse, specialized and detailed. Accordingly, new delivery methods emerged. The most widely used delivery method still is the traditional or, so called, Design-Bid-Build (DBB) approach (Molenaar & Songer, 1998; Konchar & Sanvido, 1998). In this approach, the owner initially hires a designer/engineer to prepare the bidding documents, including the design, specifications, and other required reports such as a geotechnical report or environmental assessment. Interested contractors then submit their proposals based on this bid package. Normally the lowest bid is selected for the construction of the project, but the criteria may vary from case to case. During construction, the designer has very little communication with the constructor that is limited to answering the queries regarding design on behalf of the owner (CMAA, 2012). Such specialization and sequential nature of design and construction in DBB causes fragmentation of professionals from different disciplines, creating inefficiency, and lack of interoperability (Mollaoglu-Korkmaz et al. 2014). Realizing the significance of these issues, a new set of delivery methods has emerged over time. These approaches aim at improving collaboration amongst the parties of the project. Examples include Construction Management at Risk (CM at risk), Design-Build (DB), and Integrative Project Delivery (IPD).

Recently Franz and Leicht (2016) have argued that project delivery methods are no longer relevant in predicting project performance. They recognized delivery methods based on following characteristics: i) Number of contracts held by the owner (i.e., a single contract for both design and construction, such as in DB, Vs DBB); ii) timing of involvement of contractor (i.e., high and early involvement, such as in IPD, vs low and late involvement, such as in DBB) iii) Selection criteria of contractors and sub-contractors (i.e., low bid, qualification based, and best value) iv) terms of payment (i.e., open book, lump sum, and unit price). These characteristics were utilized in this study to analyze the impact of delivery methods on SMM knowledge in AEC project teams.

#### **4. Methods**

The study focused on two main objectives: i) To perform a critical review of the SMM literature, and develop a framework categorizing its constructs, and ii) To examine the AEC project delivery attributes via the lens of this new SMM framework.

A literature review was first carried out to perform the synthesis of SMM. The primary sources for this search were the online engines, and databases: ProQuest, Web of Science, and Google Scholar. The following keywords were used for this search: *Shared Mental Models*, and *Team Mental Models*. The initial search resulted in 156 findings. These studies were carefully reviewed for new theoretical frameworks of SMM knowledge. It was observed that most of the studies adopted frameworks proposed by other researchers, and only a handful of studies attempted to add/expand by proposing new SMM categories. Repetition of ideas was neglected, and 7 studies were found to meet the criteria. A new framework was developed covering all the categories discussed in these studies.

The new framework (named 3T) was then taken forward to define the SMM knowledge specific to AEC project teams. The importance of knowledge in each category was discussed, and an analysis was performed to highlight the potential impact of various delivery system attributes on SMM development in AEC project teams. The delivery system characteristics given by Franz and Leicht (2015) were used for this purpose.

## 5. Results

The SMM construct has been evolving since Rouse et al. (1992) presented the three types: equipment knowledge; task knowledge; and team knowledge. Several researchers have proposed their own SMM types following that. Table 2 lists these studies with a brief description of each. Much of the content appears to be repetitive in each study. The most commonly recognized shared mental model categories are the one given by Mathieu et. al. (2000): task related mental models, and team related mental models. Standifer et al. (2006) proposed a new type related to entrainment called **temporal models**. They placed it as a sub-category of team related mental models. Santos et. al. (2015) and Mohammed et al. (2015) have identified it as an independent third class, in addition to team related and task related mental models.

**Table 2** Shared Mental Model Categories in the Literature.

Contributors	SMM Categories	Description
Rouse et.al. (1992)	· Equipment Knowledge	Characteristics, functioning and patterns
	· Task Knowledge	Procedures, strategies and methodologies
	· Team Knowledge	Roles, relationships and temporal patterns
Cannon-Bowers et.al. (1993)	· Equipment	Tools and Technology
	· Task	Procedures, strategies and methodologies
	· Team Interaction	Roles, responsibilities, relationships and patterns
	· Team	Skills, habits, behavior
Mathieu et. al. (2000)	· Task related	Includes Task and Equipment of Cannon-Bowers et. al. (1993)
	· Team Related	Includes team interaction and team of Cannon-Bowers et. al. (1993)
Fiore et. al. (2001)	· Task	Team task information
	· Team	Other team mates' roles and responsibilities
	· Potential Situations	Information about potential situations that may arise
Standifer & Bluedorn (2006)	· Temporal mental model	· Cycle (One complete implementation)
		· Pace (Speed)
		· Time Orientation (The interpretation of time)
Johnson et al. (2007)	· General Knowledge	The knowledge that is not team or task dependent, like communication
	· Task knowledge	Knowledge related to team tasks. Depends upon team objectives.
	· Team Knowledge	Skills and behaviors of other team members
Santos et.al. (2015)	· Dimension related to tasks	Company information, rules etc.
	· Dimension related to teams	Trust and mutual support
	· Dimension related to time	Time interpretation, planning

It was observed that much of what the researchers proposed was overlapping, and all the established scope related to shared mental models can be easily covered in three main categories: task models, team models and temporal models. In this paper, we named them the 3 T's of shared mental models (Figure 2).

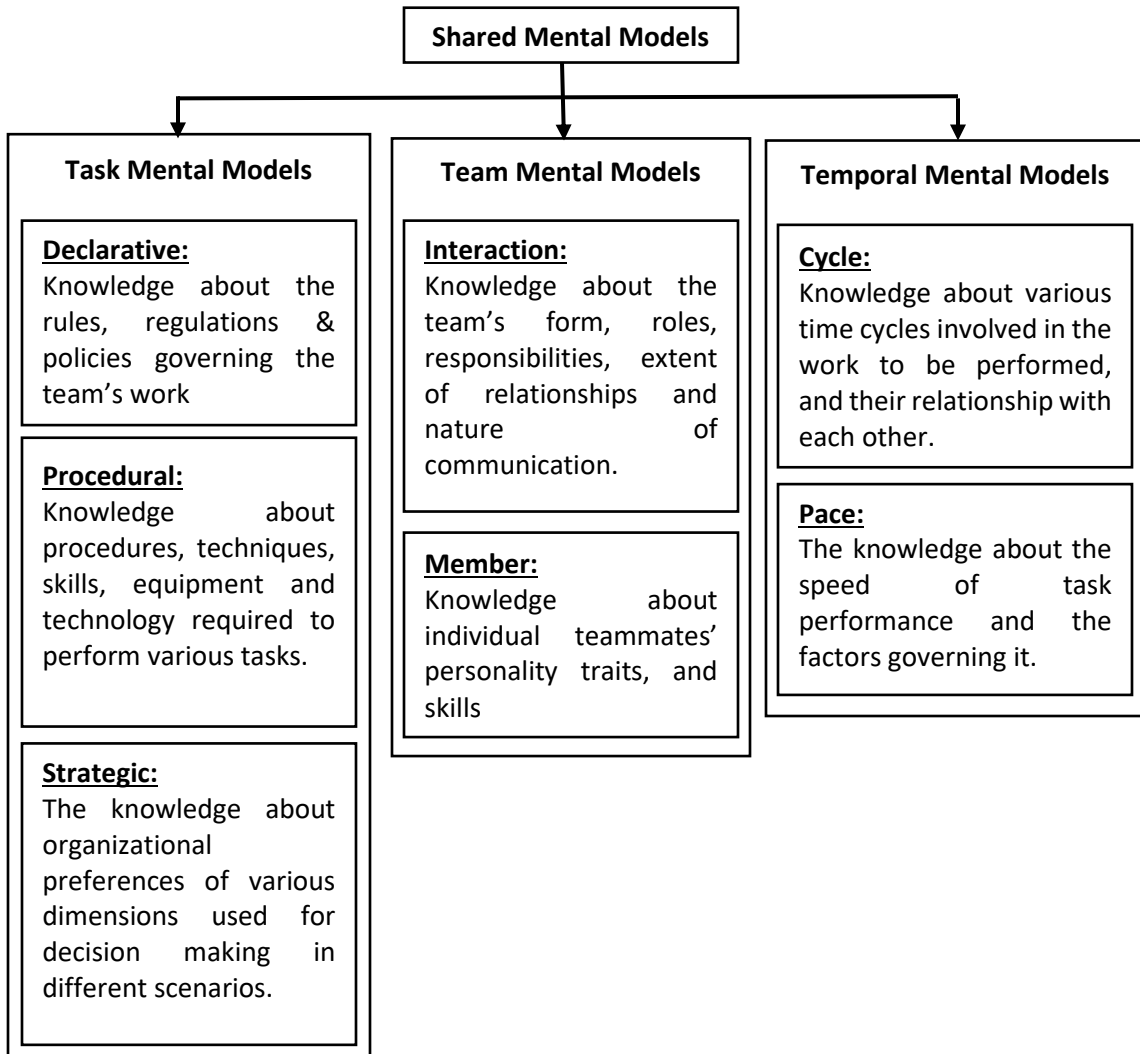
The following sections discuss each category of the 3T SMM model in detail, and simultaneously describe the implications of project delivery methods on each knowledge type.

### 5.1. Task Mental Models

This category covers all the task related knowledge. This includes rules, regulations, procedures, machine skills, and the strategies to cope with various technical issues. Task mental models can be further divided into three sub-categories.

#### a) **Declarative Mental Models**

Declarative mental models include all the knowledge related to rules, regulations, standards, and policies. Some of these elements for AEC projects are, company rules/regulations (e.g., code of conduct, benefits, evaluation procedures, penalties for misconduct, and flexibility of work hours), government regulations (e.g., tort law, work permits, equipment permits, quota for minorities/women), and various standards/codes (design, safety, construction, units of measurement). Declarative knowledge is very important for AEC projects. Setting up rules for the project, and making all team members aware of them creates team cohesion (Whatley, 2009). The regulations help in standard compliance, and hence ensure performance (Baxendale & Jones, 2000). Also, one of the major causes of delay in construction projects is legal dispute between the stakeholders (Assaf & Al-Hejji, 2006).





## **Figure 2. - 3T framework featuring the scope of Shared Mental Models**

*Implications of Project Delivery Attributes:* Project delivery systems are deemed to have a major impact on the declarative mental models. Early involvement of clients and designer in construction process has been related to better rules and regulations compliance (Baxendale & Jones, 2000). Similarly, a single contract for both design and construction (such as in design-build) helps in reducing the documentations and formalities. It also scales down the risk of legal conflicts (Chan, 2000). Finally, the quality based prequalification and selection of contractors takes in the criteria of competence and experience (Sawyer et al., 2015) which ensures that the party is already well-versed with the industry standard legal obligations and regulations required by the client.

### **b) Procedural Mental Models**

Procedural mental models include knowledge of skills, procedures, techniques, equipment and technology. The AEC projects consist of many phases, which require very diverse procedural knowledge. For AEC projects, some elements of this knowledge are the engineering and project management skills, the correct interpretation of the contract, the software skills required in design and construction, the knowledge of standard operating procedures/project specifications, the knowledge regarding various dimensions (cost, schedule, quality, safety, environment) of the project. Errors in construction and rework are very common on construction projects, and are known to cause delay and incur extra costs (Assaf & Al-Hejji, 2006). Skills shortage, incompetence, and Lack of education regarding the procedural knowledge are key issues impeding the performance on construction projects (Chang-Richards et al., 2017; Lindhard & Larsen, 2016; Sawacha et al., 1999) The research has recommended standardizing the operating procedures in construction for better performance (Nakagawa, 2005).

*Implications of Project Delivery Attributes:* To perform, the teams require sharing of knowledge regarding skills and procedures (Stevens & Campion, 1994; Stout et al., 1999). A single contract for design and construction (such as in design-build) ensures effective communication and better team integration (Mollaoglu-Korkmaz et al., 2011), and thus better knowledge sharing (van & de Ridder, 2004). Similarly, the experience and past performance of the contractor, which ensure quality of procedural knowledge, are indicators of superior performance (Alzahrani & Emsley, 2013). This clearly shows the advantages of quality based selection of contractors and sub-contractors.

### **c) Strategic Mental Models**

Strategic mental models are the sharing of preferences amongst the team members while making decisions in various scenarios. Typically, strategic decisions are based upon the organization's preferences for project dimensions like cost, schedule, quality, safety and environment. Low speed of decision making involving all teams has been categorized as one of the major causes of project delays in construction (Chan & Kumaraswamy, 1997).

*Implications of Project Delivery Attributes:* The way project delivery is designed plays an important role in enhancing strategic knowledge and decision making. A single contract for design and construction (such as design-build) naturally improves the decision making, and ensures a fast track delivery (Chan, 2000). Similarly, early involvement of stakeholders, including the contractor, helps making informed decisions, and results in a swift and effective delivery process (Forgues et al., 2012).

## **5.2. Team Mental Models**

Team mental models focus on the knowledge related to the team itself. Like Task Mental Models, Team Mental Models are also positively related to team performance (Mathieu et al., 2000). The team related knowledge is divided into two main categories.

### **a) Interaction Mental Models**

Interaction mental models cover the knowledge regarding the roles and responsibilities of team members, their inter-dependence, the nature of their interactions, and communication channels (Mathieu et al., 2000). For effective team performance, it is very important to clarify the team members' roles and responsibilities (Stout et al., 1999). In construction industry, specifically, labelling the responsibilities is one of the major challenges (Hughes & Murdoch, 2001). Also, a positive interdependence between the team members helps teams perform and achieve goals more effectively (Johnson & Johnson, 1999; Page & Donelan, 2003).

*Implications of Project Delivery Attributes:* Project delivery process can ensure better understanding of interaction amongst the team members. A single contract for design and construction (such as in design-build) makes the communication direct between the client and the contractor. Also, the responsibilities are clearer, and there are better working relationships between the team members (Chan, 2000). At the same time, it is important to note that in the case of design-build, the contract does not create roles at the lower level for micro-management like design-bid-build. Thus, the flexibility with the contractor can end up in confusion related to roles if not handled properly. Early involvement of parties, and collaborative efforts like design charrettes, clarify the roles of each member, and develops shared project goals (Mollaoglu-Korkmaz et al., 2011).

### **b) Member Mental Models**

Member mental models are related to other team members' skills, attitudes, behaviors, orientations and knowledge. (Mathieu et al., 2000). They help team members in predicting behaviors, dealing with other team mates in the best suited manner, and providing appropriate information at the right time. Member Mental Models become specifically important in case of flexible and dynamic work, as requirements, and expectations play a bigger role then (Cannon-Bowers et al., 1993).

*Implications of Project Delivery Attributes:* Delivery systems and collaborative approach can help develop and maintain the member mental models. A single contract for design and construction (such as in design-build) cuts down the numbers of stakeholders, and creates better working

relationships (Chan, 2000). Communicating and knowing your team members is an established team building tool (Page & Donelan, 2003). Bringing stakeholders together from the beginning helps them in getting familiar with each other, and thus ensures a stronger team. Traditional price based selection of contractors cultivates the opportunistic behavior. Qualification based selection is used to cope with this problem, and encourage more professional behavior from the contractors (Lo & Yan, 2009). Also, the quality based selection of the contractor incorporates experience and past performance, which provides a log of good behaviors for client, and improves trust, and predictability.

### **5.3. Temporal Mental Models**

Temporal mental models have been recognized as a separate category of SMMs recently (Santos et al., 2015; Mohammed et al., 2015). Temporal Mental Models deal with time related knowledge amongst the team members. We have divided Temporal Mental Models into two categories: Cycle Mental Models and Pace Mental Models (Standifer et al., 2006). Time related conflicts are major cause of disturbance in groups, and should be addressed on priority bases (McGrath & Tschan, 2004).

#### **a) Cycle Mental Models**

Cycle mental models cover the knowledge about entrainment cycles existing inside the system (Standifer et al., 2006). For projects, it includes the information of activities, schedules, and milestones. It is very important for the team members to be on the same page of temporal sequencing. Knowing what comes first and what comes afterwards helps team members to coordinate in a synchronized manner (Mohammed et al., 2015).

*Implications of Project Delivery Attributes:* For a project delivery with a single contract for design and construction (such as in design-build), there is less documentation and formalities. Contractor has more flexibility, as it is responsible for the complete work (Chan, 2000). Therefore, there is better scheduling and time performance (Hale et al., 2009). Moreover, the early involvement of contractor (and other stakeholders) creates more integration and goal alignment (Mollaoglu-Korkmaz et al., 2011). This reduces the conflicts amongst the project participants, which has a decrementing effect on schedule performance. Also, the competence of Project Manager is a major indicator of good scheduling, therefore quality based selection of contractor is favorable for cycle mental models (Iyer & Jha, 2006).

Having proposed that, it is also important to note that the cycles in design-build can become relatively complicated in nature due to overlap of design and construction, and the overall cycle mental model will expand in its content for the team performing at that point.

#### **b) Pace Mental Models**

Pace mental models include the knowledge of speed of task performance, and the factors governing it (Standifer et al., 2006). Deadlines and milestones are a couple of major factors that influence the definition of pace for tasks (Lindkvist et al., 1998). Another factor which defines the pace is the

time orientation, which defines how people in various cultures define, percept and measure time (McGrath & Tschan, 2004; Standifer et al., 2006).

*Implications of Project Delivery Attributes:* Contract with a single party for both design and construction (such as in design-build) is empirically proven to ensure better and sustained pace, and consequently shorter project durations (Hale et al., 2009). Bringing the contractor early promotes communication, improves group cohesion, and reduces RFI's/conflicts for a smoother pace (Mollaoglu-Korkmaz et al., 2011). Communication among the project participants at all stages is a key indicator of better time efficiency and sustainable pace (Takim and Akintoye, 2002). Finally, a more competent contractor ensures smoother performance, and less conflicts/interruptions (Lo & Yan, 2009) ensuring a smoother, well-maintained pace.

The scope of knowledge in SMMs is still expanding, and new categories and knowledge types will become a part of the construct in future. One such example is the belief system. Also, there is a notion amongst some researchers (Mohammed et al., 2010) that the belief structure should also be included in the shared mental model content with knowledge. Though we came across no study exploring this area yet.

## **6. Discussion**

The first challenging task at hand was to capture the scope of SMM content. After a thorough investigation of the literature, we succeeded in proposing a framework that includes all types of SMMs proposed by researchers in the past. This is a complete representation so far, and will expand in the future as new mental model types emerge – like the belief structure, which is proposed, but not developed as a type yet (Mohammed et al., 2000).

The paper also contributes significantly towards the AEC project literature. There is evidence available for long that different parties of the project in AEC lack a common understanding of various project aspects (Forbes, 1999), and the clear meeting of minds of the parties is immensely important for better performance (Dissanayaka & Kumaraswamy, 1999). Yet, the subject of implicit coordination through team cognition remains undiscovered. This study will serve as an important milestone in AEC research, by delivering the foundation for SMM studies for AEC projects.

Based on the findings presented in the previous section, a connection between AEC projects and SMMs has been successfully established, which paves the way for application of this renowned psychological concept, as a tool for performance improvement. The types of knowledge to be shared amongst the team members in AEC projects have been explicitly identified for each of the 3 T's of SMM: task, team, & temporal. The managers and team leaders can utilize this for tracking the mental models of their teams. Also, trainings have been designed for achieving SMM similarity and quality in teams for other areas (e.g. Smith-Jentsch et al., 2008). As the holistic knowledge for SMMs in the AEC project teams has been identified, studies can now be conducted to design more effective and comprehensive trainings.

## **7. Conclusion**

SMM is a well-established, and highly regarded concept in the psychology of cognition that has not been utilized, in its true spirit, for complicated systems like AEC project teams so far. This study was designed to discover the untapped potential of SMMs in theory, and analyze their

usefulness in the context of AEC project teams. The results provided with useful contributions for the literature and practice alike.

There are two major contributions of this study to the literature: the 3T framework of SMMs, and the SMM knowledge in AEC projects (with the impact of delivery method variation). The study contributes to the literature of both team psychology and AEC projects. Also, the findings have practical implications as explained in the discussions section above.

Limitations to this work exist. This research was limited to analyze the impact of only delivery method attributes on SMMs. The list of factors in AEC, that can potentially impact the SMM knowledge, is very long. It is important to perform similar analysis with respect to other factors that can potentially impact the SMMs (such as technology, cultural boundaries, and nature of projects). We also realize the possibility of other psychological agents, working in parallel, and affecting the performance indications in the proposed studies. Therefore, we suggest an investigation into the psychological literature to identify any such agents and incorporate their effect into the studies for reliable results.

With our findings, we hope to open new chapters of research and practice for inter-organizational projects in general, and AEC projects in particular. SMMs can be the answer to how team integration and cohesion relate to performance of the teams and projects. With the knowledge categorized and defined, future research should focus on developing the tools to measure SMMs in AEC inter-organizational project teams.

## 8. References:

- AIA (American Institute of Architects). (2010). *Integrated Project Delivery: Case Studies*. AIA California Council. Sacramento, CA.
- Alarcón, L. F., & Mesa, H. H. (2014). A conceptual framework to model the performance of project delivery systems. *eWork and eBusiness in Architecture, Engineering, and Construction*, 603–608
- Alzahrani, J., & Emsley, M. (2013). The impact of contractors' attributes on construction project success: A post construction evaluation. *International Journal of Project Management*, 31(2), 313-322.
- Assaf, S. A. & Al-Hejji, S. (2006) Causes of delay in large construction project. *International Journal of Project Management*, 24, 349–357.
- Avnet, M. S., & Weigel, A. L. (2013). The structural approach to shared knowledge: An application to engineering design teams. *Human Factors*, 55(3), 581-594.
- Baiden, B. K., & Price, A. D. F. (2011). The effect of integration on project delivery team effectiveness. *International Journal of Project Management*, 29(2), 129-136.
- Baxendale, T. & Jones, O. (2000) Construction design and management safety regulations in practice - progress on implementation, *International Journal of Project Management*, 18 (1), 33-40

- Blickensderfer, E. L., Reynolds, R., Salas, E., & Cannon-Bowers, J. (2010). Shared expectations and implicit coordination in tennis doubles teams. *Journal of Applied Sport Psychology*, 22(4), 486-499.
- Cannon-Bowers, J. A., Salas, E. & Converse, S. A. (1990). Cognitive psychology and team training: Shared mental models in complex systems. *Human Factors Bulletin*, 33, 1-4.
- Cannon-Bowers, J., Salas, E., & Converse, S. (1993). Shared mental models in expert team decision making. In N. J. Castellan Jr. (Ed.), *Individual and group decision making: Current issues*. (pp. 221-246) Lawrence Erlbaum Associates, Inc, Hillsdale, NJ.
- Chan, A. P. C. (2000) Evaluation of enhanced design and build system a case study of a hospital project, *Construction Management and Economics*, 18(7), 863-871.
- Chan, D. W. M., & Kumaraswamy, M. M. (1997). A comparative study of causes of time overruns in hong kong construction projects. *International Journal of Project Management*, 15(1), 55-63.
- Chang-Richards, Y., Wilkinson, S., Seville, E., & Brunsdon, D. (2017). Effects of a major disaster on skills shortages in the construction industry. *Engineering, Construction and Architectural Management*, 24(1), 2-20.
- CMAA (Construction Management Association of America) (2012) An Owners' Guide To Project Delivery Methods. [PDF] Retrieved from <https://cmaanet.org>
- DeChurch, L.A. & Mesmer-Magnus, J. (2010a) Measuring shared team mental models: A meta-analysis. *Group Dynamics: Theory, Research, and Practice*, 14(1), 1-14.
- DeChurch, L. A., & Mesmer-Magnus, J. (2010b). The cognitive underpinnings of effective teamwork: A meta-analysis. *Journal of Applied Psychology*, 95(1), 32-53.
- Dissanayaka, S. M., Kumaraswamy, M. M. (1999). Reconstructing procurement systems and team relationships. *Int. J. Comput. Integr. Design Construct.*, 1(2), 10-19.
- Duysters, G., & de Man, A.P. (2002) Organizational models for collaboration in the new economy. *Human Resource Planning* 25 (4), 7-18.
- Edwards, B.D., Day, E.A., Arthur, W., Jr & Bell, S.T. (2006) Relationships Among Team Ability Composition, Team Mental Models, and Team Performance, *Journal of Applied Psychology*, 91(3), 727-736.
- Fiore, S. M., Salas, E., & Cannon-Bowers, J. (2001). Group dynamics and shared mental model development. In M. London (Ed.), *How people evaluate others in organizations*. (pp. 309-336) Lawrence Erlbaum Associates Publishers, Mahwah, NJ.
- Forbes, L. H. (1999). *An engineering management-based investigation of owner satisfaction, quality and performance variables in health care facilities construction* (Order No. 9938323). Available from ProQuest Dissertations & Theses Global. (304539302).
- Forbes, L. H. and Ahmed, S. M. (2011) *Modern construction; lean project delivery and integrated practices*. Boca Raton, FL: CRC Press
- Forgues, D., Iordanova, I., Valdivesio, F., & Staub-French, S. (2012) Rethinking the Cost Estimating Process through 5D BIM: A Case Study, *Construction Research Congress 2012*, West Lafayette, Indiana, May 21-23, 2012. Reston, VA: ASCE

- Franz, B. W., & Leicht, R. M. (2016). An alternative classification of project delivery methods used in the united states building construction industry. *Construction Management and Economics*, 34(3), 160-173.
- Franz, B., leicht, R., Molenaar, K., & Messner, J. (2016) Impact of Team Integration and Group Cohesion on Project Delivery Performance. *Journal of Construction Engineering and Management*, 143(1), 1-12.
- Hale, D. R., Shrestha, P. P., Gibson, G. E., & Migliaccio, G. C. (2009) *Empirical Comparison of Design/Build and Design/Bid/Build Project Delivery Methods*. *Journal of Construction Engineering and Management*, 135(7), 579-587.
- Hsu, J. S., Liang, T. P., Wu, S. P. J., Klein, G., & Jiang, J. J. (2011). Promoting the integration of users and developers to achieve a collective mind through the screening of information system projects. *International Journal of Project Management*, 29(5), 514-524.
- Hughes, W. and Murdoch, J. R. (2001) *Roles in construction projects: analysis and terminology*. Construction Industry Publications, Birmingham
- Graham, J., Schneider, M., Bauer, A., Bessiere, K., & Gonzalez, C. (2004). Shared mental models in military command and control organizations: Effect of social network distance. Paper presented at the 509-512.
- Iyer, K. C., & Jha, K. N. (2006) Critical Factors Affecting Schedule Performance: Evidence from Indian Construction Projects. *Journal of Construction Engineering and Management*, 132(8), 871-881.
- Johnson, D. W., & Johnson, R. T. (1999). *Learning Together and Alone: Cooperative, competitive, and individualistic learning* ( 5th ed.). Needham Heights: Massachusetts: Allyn and Bacon.
- Johnson, T. E., Lee, Y., Lee, M., O'Connor, D.,L., Khalil, M. K., & Huang, X. (2007). Measuring sharedness of team-related knowledge: Design and validation of a shared mental model instrument. *Human Resource Development International*,10(4), 437-454.
- Jones, C. & Lichtenstein, B. B. (2008) Temporary inter-organizational projects: how temporal and social embeddedness enhance coordination and manage uncertainty. In: Cropper, S., Ebers, M., Huxham, C., Smith Ring, P. (Eds.), *The Oxford Handbook of Inter-Organizational Relations*. (pp. 231–255). Oxford, UK: Oxford University Press
- Khairil, I. I., Costello, S. B., & Wilkinson, S. (2013). Key practice indicators of team integration in construction projects: A review. *Team Performance Management*, 19(3), 132-152.
- King, M., & Phythian, G. J. (1992). Validating an expert support system for tender enquiry evaluation: A case study. *The Journal of the Operational Research Society*, 43(3), 203.
- Klimoski, R., & Mohammed, S. (1994). Team mental model: Construct or metaphor? *Journal of Management*, 20(2), 403.
- Konchar, M., & Sanvido, V. (1998) Comparison of U.S. project delivery systems. *Journal of Construction Engineering and Management*, 124(6), 435–444.
- Levesque, L. L., Wilson, J. M., & Wholey, D. R. (2001). Cognitive divergence and shared mental models in software development project teams. *Journal of Organizational Behavior*, 22(2), 135-144.

- Lindhard, S., & Larsen, J. K. (2016). Identifying the key process factors affecting project performance. *Engineering, Construction and Architectural Management*, 23(5), 657-673.
- Lindkvist, L., Soderlund, J., & Tell, F. (1998). Managing product development projects: On the significance of fountains and deadlines. *Organization Studies*, 19(6), 931-951.
- Lo, W. & Yan, M. (2009) Evaluating Qualification Based Selection System: A Simulation Approach. *Journal of Construction Engineering and Management*, 135(6), 458-465
- Mathieu, J.E., Heffner, T.S., Goodwin, G.F., Salas, E. & Cannon-Bowers, J. (2000), The influence of shared mental models on team process and performance, *Journal of Applied Psychology*, 85(2), 273-283.
- Mathieu, J. E., Heffner, T. S., Goodwin, G. F., Cannon-Bowers, J., & Salas, E. (2005). Scaling the quality of teammates' mental models: Equifinality and normative comparisons. *Journal of Organizational Behavior*, 26(1), 37-56.
- McGrath, J. E., & Tschan, F. (2004). *Temporal matters in social psychology: Examining the role of time in the lives of groups and individuals*. American Psychological Association, Washington, DC.
- Mohammed, S., & Dumville, B. C. (2001). Team mental models in a team knowledge framework: Expanding theory and measurement across disciplinary boundaries. *Journal of Organizational Behavior*, 22(2), 89-106.
- Mohammed, S., Ferzandi, L. & Hamilton, K. (2010) Metaphor no more: A 15-year review of the team mental model construct", *Journal of Management*, 36(4), 876-910.
- Mohammed, S., Hamilton, K., Tesler, R., Mancuso, V., & McNeese, M. (2015). Time for temporal team mental models: Expanding beyond “what” and “how” to incorporate “when”. *European Journal of Work and Organizational Psychology*, 24(5), 693-709.
- Molenaar, K.R. and Songer, A.D. (1998). Model for Public Sector Design-Build Project Selection. *Journal of Construction Engineering and Management*, 124(6), 467-479.
- Mollaoglu-Korkmaz, S., Swarup, L., & Riley, D. (2011). Delivering sustainable, high-performance buildings: Influence of project delivery methods on integration and project outcomes. *Journal of Management in Engineering*, 29(1), 71-78.
- Mollaoglu-Korkmaz, S., Miller, V. D., and Sun, W. (2014). “Assessing key dimensions to effective innovation implementation in interorganizational project teams: An Integrated Project Delivery case.” *Eng. Proj. Organ. J.*, 4(1), 17-30.
- Nakagawa, Y. (2005) Importance of Standard Operating Procedure Documents and Visualization to Implement Lean Construction, 13th International Group for Lean Construction Conference, Sydney, 2005. Sydney: International Group on Lean Construction.
- Page, D. & Donelan, J. G. (2003) Team-Building Tools for Students, *Journal of Education for Business*, 78(3), 125-128.
- Rico, R., Sánchez-Manzanares, M., Gil, F., & Gibson, C. (2008). Team implicit coordination processes: A team knowledge-based approach. *Academy of Management Review*, 33(1), 163-185.



- Rouse, W.B., Cannon-Bowers, J. & Salas, E. (1992) The role of mental models in team performance in complex systems, *IEEE Transactions on Systems, Man, & Cybernetics*, 22(6), 1296-1308.
- Salas, E., Sims, D.E. & Burke, C.S. (2005) Is there a "Big Five" in Teamwork? *Small Group Research*, 36(5), pp. 555-599.
- Santos, C.M., Uitdewilligen, S. & Passos, A.M. (2015) A temporal common ground for learning: The moderating effect of shared mental models on the relation between team learning behaviours and performance improvement, *European Journal of Work and Organizational Psychology*, 24(5), 710-725.
- Sawacha, E., Naoum, S., & Fong, D. (1999). Factors affecting safety performance on construction sites. *International Journal of Project Management*, 17(5), 309-315.
- Sawyer, J. T., Brian, M. S., Perrenoud, A. J., Smithwick, J. B. & Sullivan, K. T. (2015) *Qualifications-Based Selection of Construction Services: Evaluation Criteria That Best Differentiate Contractor Qualifications*. Paper presented in the 51st ASC Annual International Conference, Texas A & M. Fort Collins, CO: Associated Schools of Construction.
- Smith-Jentsch, K., Campbell, G. E., Milanovich, D. M., & Reynolds, A. M. (2001). Measuring teamwork mental models to support training needs assessment, development, and evaluation: Two empirical studies. *Journal of Organizational Behavior*, 22(2), 179-194.
- Smith-Jentsch, K., Cannon-Bowers, J., Tannenbaum, S. I., & Salas, E. (2008). Guided team self-correction: Impacts on team mental models, processes, and effectiveness. *Small Group Research*, 39(3), 303–327.
- Standifer, Rhett, and Allen Bluedorn. (2006) Alliance Management Teams and Entrainment: Sharing Temporal Mental Models. *Human Relations*, 59(7), 903-27.
- Stevens, M. J., & Campion, M. A. (1994). The knowledge, skill, and ability requirements for teamwork: Implications for human resource management. *Journal of Management*, 20(2), 503-530.
- Stout, R. J., Cannon-Bowers, J. A., Salas, E., & Milanovich, D. M. (1999). Planning, shared mental models, and coordinated performance: An empirical link is established. *Human Factors*, 41, 61–71.
- Takim, R and Akintoye, A (2002) Performance indicators for successful construction project performance. In: Greenwood, D (Ed.), *18th Annual ARCOM Conference*, 2-4 September 2002, University of Northumbria. Association of Researchers in Construction Management, Vol. 2, 545-55.
- Waller, M.J., Gupta, N. & Giambatista, R.C. (2004) Effects of Adaptive Behaviors and Shared Mental Models on Control Crew Performance, *Management Science*, 50(11), 1534-1544.
- Wegner, D. M. (1987). Transactive memory: A contemporary analysis of the group mind. In B. Mullen & G. R. Goethals (Eds.), *Theories of group behavior* (pp. 185–205). New York, NY: Springer–Verlag.
- Whatley, J. (2009). Ground rules in team projects: Findings from a prototype system to support students. *Journal of Information Technology Education*, 8, 161-176.