A FRAMEWORK TO ANALYZE THE EFFECTIVENESS OF TEAM INTERACTIONS IN VIRTUAL ENVIRONMENTS

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ABSTRACT: Appropriate technology use has been shown to provide added value for team collaboration in the design and construction process. Evidence of this value has been demonstrated and measured using various techniques, ranging from the perception-based surveys of individuals involved in tasks to measured results of the collaborative tasks. Recently, several studies have focused on the effectiveness of these collaborations by measuring the different aspects of the discussion during team meetings. The measures of effectiveness employed, however, have focused primarily on the content of the discussions as a means of measuring the effectiveness. This paper explores the application of various coding schemes and metrics to quantitatively measure team performance during tasks which are performed in virtual environments and interactive workspaces. The proposed metrics are developed from theories in several related fields to show the opportunities for expanding the methodologies to measure the impact of virtual environment interaction. Finally, the framework is presented with measures to include the impacts of the virtual environment, and provide metrics which can be used to rate the level of effectiveness of team collaboration.

KEYWORDS: virtual environments, coding, collaboration, communication.

1. INTRODUCTION

The use of virtual environments, in conjunction with appropriate software applications and data models, offers the potential to improve teamwork. A virtual environment (VE) is an environment which is partially or totally based on computer generated sensory inputs (Air Force, 1994). While the term virtual environment has been used quite extensively in conjunction with virtual reality systems, there is inherent ambiguity in the definition. As the definition suggests, virtual environments bring together a real, physical environment which the user utilizes to interact with a computer simulated environment. The challenge is that, by definition, a virtual environment is the bringing together, and often the blurring of the lines, between the physical and digital environments. In order to discuss the traits of a virtual environment, the physical traits of the facilities employed will be referred to as the interactive workspace (IW) and the computer simulated aspects will be referred to as the digital virtual environment (DVE). The merging of these two is considered the virtual environment as a whole.

It has been documented that virtual environments contribute to improved visualization (Tan, 2005) and communication (Cruz-Neira et al, 1993), among other benefits, yet it is still difficult to quantify the value of a VE. Conceptual benefits have been identified, but for many tasks these benefits remain to be clearly quantified and related to the contributing aspects of the VE. This quantification of benefits could inform future decisions regarding investments in VEs, aid in the identification of VE attributes that provide the most value, and identify the most appropriate processes and tasks to be performed within these environments.

Through initial studies, it has been found that a significant portion of the benefits for using VEs for tasks within the design and construction industry are focused on the use of these environments to support team design and decision making tasks (Gopinath, 2004). Yet, it is difficult to clearly identify the benefits in both efficiency and effectiveness as they relate to team task performance. Defining these benefits and clearly relating them to characteristics of the VE, whether digital or physical in origin, would provide a means for comparison amongst different VEs, as well as allow for clear definitions of when and how VEs should be employed. Therefore, a new framework and metrics for performance in virtual environments is proposed in this paper.

2. MEASURING TEAM COLLABORATION IN VIRTUAL ENVIRONMENTS

When searching for this new framework, a detailed review of the Architectural, Engineering, and Construction (AEC) related literature was performed focusing mainly on the consideration of display and software impact. Following the review of the AEC literature, a more comprehensive review was performed to identify concepts from other disciplines which could be employed to expand the current data collection and research methodologies in use.

2.1 Frameworks and Metrics from the AEC Community

There is literature within the AEC domain indicating measured values for the use of display systems when performing design and construction planning meetings (Liston, 2000; Gopinath and Messner, 2004). The literature provides a strong base for quantitatively coding team discussions, as well as comparing team interactions. However, the original frameworks and coding schemes found are primarily used on design and construction progress meetings. While these meetings offer a strong start and reference for evaluating team interactions, these studies did not quantitatively measure the use of the display media or software attributes as they were employed in the meetings. Further review found expanded frameworks for evaluating the conversations as well as more collaborative uses of design spaces. Maldovan et al (2006) used an immersive virtual environment and 4D simulation to for a construction schedule review meeting. While the task was more problem solving focused and considered the use of the display, the study does not track the role that the immersive display and software played in the team interactions.

Wang et al (2007) performed a comparative observational study to discern the role that software played when using a virtual environment for team problem solving for a construction scheduling task. The study was focused on determining the impact of the manner in which groups interact with a 3D building model when developing a schedule. The study found interesting results and implications about improving software for detailed sequence planning, but the virtual environment employed was the same in both subsets of data, and the interaction was not specifically tracked in the framework.

In a shift toward tracking the impact of VEs in collaborative settings, Andrews et al (2006) developed a system for measuring the use and the manner in which a VE is used during problem solving. They consider the team at different stages and using VE resources. While the steps are significant toward evaluating the use of a VE, the system does not differentiate between the software and the media interaction. Issa et al (2006) continued with this system, employing it in a problem solving context, but in the study the VE tools use was not specifically tracked and could not be directly correlated to their value to the meeting. In a further development, Fard (2006) considers the type of the information exchanged and the form it takes. This offers a specific method for tracking the model content used in the meetings. This was a very interesting approach, yet the information was not correlated to the project discussions to demonstrate the specific value of the information. Fard also developed other metrics, including resolution rate and productivity, and the number of information forms used in an exchange for determining the overall value and effectiveness of the meeting.

Table 1: Comparison of topics considered in previous AEC research frameworks and coding schemes

Source	Meeting Purpose	Meeting Focus	Software	Metrics Used
Liston	Schedule	Schedule Review	Considered, not tracked	% time spent on 4 discussion types
Gopinath and Messner	Construction Progress	Progress review	Considered, not tracked	% time spent on 7 discussion types
Maldovan et al.	Schedule	Schedule redesign	Considered, not tracked	% time spent on 7 discussion types
Wang et al	Schedule	Detailed construction sequence design	Compared results of two programs, not tracked	% time spent on 6 discussion types
Andrews et al	Preliminary Design	Preliminary design (sustainability)	Considered	n/a
Issa et al	Preliminary Design	Preliminary design (sustainability)	Considered	n/a
Fard	Design Coordination	Design Coordination	Considered	Meeting productivity, resolution rate & productivity, # of information forms used

The current AEC literature, while offering some means and measures for considering group interaction and the value of VEs to facilitate additional interaction, is still in need of an overall framework for correlating the two. There is a definite need for a more comprehensive and versatile system for evaluating team collaboration which includes the process, the use of software and media, and metrics to evaluate the effectiveness of these interactions.

2.2 Literature on Team Collaboration

Collaboration consists of three major concepts: 1) it is a process; 2) it involves the interaction of two or more people; and 3) the people should be working together toward a common goal or outcome (Collaboration, 2007). When considering the process used in engineering problem solving, the literature reveals that there is not one consistent process commonly used. Overviews of various processes are presented by Cross (1994) and Birmingham (1997), but the common perspective is that no process is universally employed. The processes presented for engineering design tend to be linear, have well defined stages, and deal with well defined problems. The architectural design models tend to allow for more cycles of design, be more descriptive in nature, and lattice-like (Magent, 2005). With the lack of a single consistent design and collaboration process, the framework will need to be versatile to react to the process used in each case.

In their considerations of communication and thinking in design teams, Stempfle and Badke-Schaub (2002) present four cognitive operations when dealing with a problem solving task: generation, exploration, comparison, and selection. They also differentiate the concepts of individual thinking and thinking within a team. The results are two processes, one for content development for the task and one for the team process, as shown in Figure 1. They found that groups spend similar amounts of time communicating for each purpose and that the process employed to find a solution is often a satisficing process, rather than an optimizing one. The suggestion presented is that satisficing is time saving and suggested for simpler or well defined tasks with the use of more structured and rigorous methods for ambiguous or complex tasks. The framework will need to measure conversation about both the task use of a VE as well as the process planning steps to determine if and how a VE may contribute to both optimizing and satisficing operations.

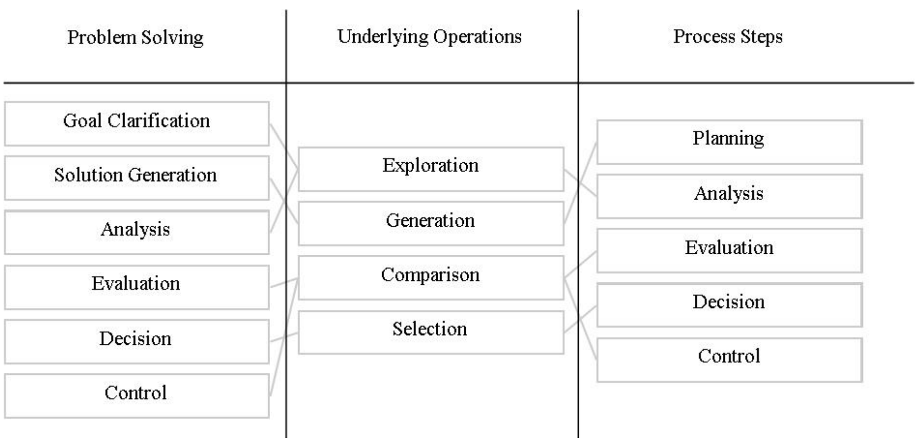

Figure 1: Generic step model of design team activities (adapted from Stempfle and Badke-Schaub, 20002).

In Time, Interaction, and Performance (TIP) Theory the group interaction focuses on the temporal interactions of groups and their performance (McGrath, 1991). It states that groups perform three simultaneous activities as they work: production, group well-being, and member support. Within any one of these functions, groups can be in four possible stages: inception, problem solving, conflict resolution, and execution (Weick and Meader, 1993). Within one of these stages, the group could be employing one of two purposes, conveying information or converging on a shared meaning (Moscovici, 1980). The tracking of the activities and stages, as well as the use for conveying information or converging on shared meaning, can help define the dynamics of group interaction.

Activity theory focuses its concepts on the unity of consciousness with interaction. The base unit of study is an action which is motivated by an objective, but the system of analysis is divided into levels of activities, actions, and operations. Actions are steps in activities, while operations are unconscious reactions to changes in the environment or action (Kaptelinin, 1993). The model of a mediated act was started by Vygotsky, but has developed into the model shown in Figure 2 (Jonassen and Rohrer-Murphy, 1999). The tools considered shape the way humans interact with reality, and include two types: technical and psychological. Technical tools are those which are meant to affect physical objects, namely the interactive hardware one would use in a VE, while psychological tools are used to influence people such as the software tools and visual displays utilized for improved communication.

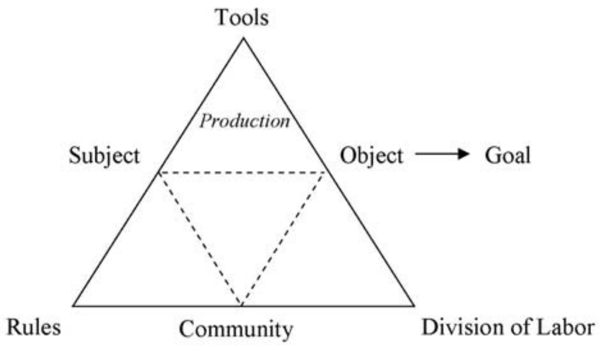

Figure 2: Structure of a human activity system (adapted from Engestrom, 1987).

The theories presented show that there are consistent properties to group interaction, but they are challenging to track due to the lack of a single consistent process. It is commonly shown that groups take into consideration the process and group structure in their discussions, the task they are performing, and to a smaller extent the underlying relationships of the group members. These can be tracked in terms of stage of development, or conflict over time. They also offer a means for differentiating the goals of different actions with regard to the uses of VE, and the basis for interpreting those actions.

2.3 Software and Media Interaction

Having determined some basis for how groups interact and the processes which they use, the next concern is how that interaction is affected by the use of different means of communication. Media Richness Theory presents a concept that task performance improves when the media ability to convey information matches the task needs (Daft and Lengel, 1986). The theory contends that media richness depends on the ability to convey natural language, contains a wider range of cues, greater personalization, and more rapid feedback. These are used to suggest that richer media are needed for tasks where more group negotiation is required, while tasks with defined direction, but little available information, benefit more from leaner levels of media richness (Daft and Weick, 1984). Media Synchronicity, proposed by Dennis and Valacich (1999), continue from the concepts posed by Media Richness. The authors propose that the richness of different media is relative to the individuals or groups employing them. They apply a more relative scale, and suggest that certain media traits are more conducive to different task purposes, as demonstrated in Figure 3. These tools offer guidelines from which the utilization of the VE can be compared for its effective use.

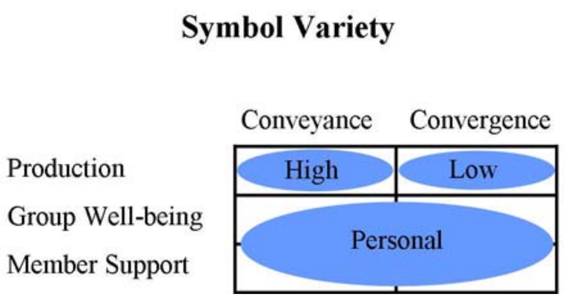

Figure 3: Example of desired media characteristics as presented (adapted from Dennis and Valacich, 1999).

In the study of Human-Computer Interaction (HCI), recent trends have suggested that the human and computer activity should be considered as individual pieces in a larger context. Incorporating new technology has been shown to create new tasks (Carroll et al, 1991). The tool mediation perspective suggests two interfaces that need to be considered: 1) the interaction between the person and the computer, and 2) the interaction between the computer and the information, or more simply, the media and the software (Kaptelinin, 1993). Technology can be the principal enabler of an activity, or it can facilitate an activity that would otherwise be nearly impossible to grasp (Kuutti, 1995).

The theories presented clearly show means by which to evaluate the use of media and software. Human-Computer Interaction theory shows the need for delineation of the software from the display media, but both still need to be considered within the context and the overall task or process goal. The theories identify potential traits and guidelines for evaluating their effective use. They also present the role that technology can play in the development process.

2.4 Evaluating Team Effectiveness

In a longitudinal study of group interaction, Jehn and Mannix (2001) tracked conflict within groups to determine how different types of conflict relate to overall group performance. In their study, they identify three types of conflict which they track: relationship conflict, task conflict, and process conflict. The level of consensus among the groups was tracked, and conflict was measured throughout the process. The outcomes presented were that all three conflict types are present throughout group interaction, but for task and process conflict there is a desired amount at certain stages which correlated with high performance by the groups, but a higher level of relationship conflict was found to be detrimental to group performance.

Structuration theory, proposed by Giddens (1984) offers a way of balancing social structures against the individuals involved through social practices. The central concept is that human action and the structure of human interaction are two sides of the same coin, and that they change over time. With the growth of technology, researchers have begun to apply these concepts to how groups interact with computers. In their study of group decision support software, Desanctis and Poole (1994) study how the appropriation of technology is central to the role it plays in group interaction and performance. They develop a detailed list of ways social structures can be used related to the applications of technology, and track technology use as a function of the structures and the long term technology trends in the group which result from the adoption of these structures.

Taking Gidden's concepts behind the adoption of social structures further, Chudoba (1999) studied the use of group decision support software and coded group activities based on the junctures of interaction rather than the conversation which took place. A juncture, as defined in the report, is an actual change in the group activity, an attempt to change the group direction or activity, or a group choice, whether spoken or through action. For example, a group may choose to use a feature of the software to perform a task or they may perform it without using the software. Conversations were coded, and they were classified by the role the juncture or activity which they contributed to, rather than the type of conversation taking place. The coding also included a brief summary of the interaction to provide a basis for what occurred at that juncture. The concepts offered provide the potential basis for correlating group processes, technology use, and team performance.

The studies of group interaction presented through other fields offer concepts of how to measure collaboration, consider the amount of input from a source, and the options for considering the actions as representative pieces to indicate the effectiveness, rather than the conversation types. Also, the interactions among group members tend to change over time, in terms of relationships and forms of communication.

3. FRAMEWORK FOR EVALUATING AND MEASURING TEAM INTERACTION

To develop a new framework for evaluating and measuring team interaction within a VE, it was necessary to start with the components which make up a VE and how a team might interact with it (see Figure 4). The physical components are the IW in which a person must be located to use the VE, the interactive devices they use, the display system, and possibly artefact(s) they may have relating to the task at hand. The DVE aspects are the virtual artefact, the virtual space in which the content is situated, and the software tools and resources which allow the use and interaction with the virtual artefact. Although the image shows the team as sharing the same physical space, another variation would be for them to share the DVE, while occupying separate interactive workspaces.

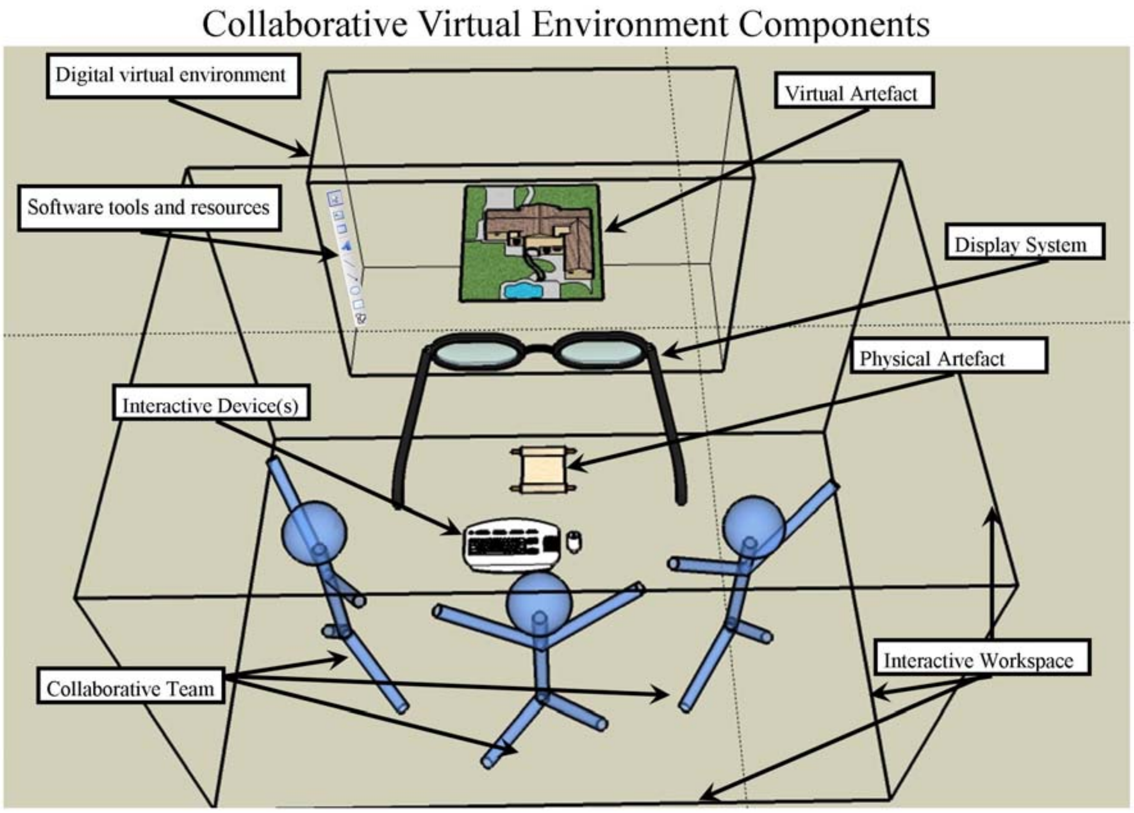

Figure 4: Components of a Collaborative Virtual Environment.

3.1 Tracking group interaction

The literature, while demonstrating an array of methods for measuring discussion in meetings, there are limited studies that demonstrate conversation which proves more effective or productive due to the impacts of VEs. The proposed discussion analysis coding scheme allows for the quantification of discussion through a focus on the context of the junctures (Chudoba, 1999) or actions (Kaptelinin, 1993) and the function of these actions (Weick and Meader, 1993). The actions, based on the functions and actions of TIP theory, shown in Table 2, will more clearly demonstrate the activities occurring when the VE is used. By tracking the activities, the objectives can be more clearly identified, and the outcomes can be measured and considered in the long term perspective of the group. The long term tracking will help to determine implementations which result in continued usage of the virtual environments which lead to better team performance overall.

Table 2: Matrix of Actions and their functions – expansion of TIP Theory to consider technology.

	Process	**Task**	**Social**	**Technology**
Inception				
Technical Problem Solving				
Conflict Resolution				
Execution				

In addition to tracking the actions, it is also important to determine the involvement of the group members in the activities. This is tracked to determine whether these are collaborative activities, or one or two group members performing the task and discussion. As shown in Figure 5, the system includes the central discussion, and the possibility of peripheral discussions. Similarly, the researcher can track central activity for someone to interact with the VE or peripheral use of the VE or other artefacts. Central activities, for both the discussion and the virtual environment interaction mean that the activity relates to the central objective the group is working toward at that time. If, for example, the group were discussing the windows and one group member is navigating the model so the group can discuss different views, it would be central interaction with the virtual environment. If the model navigation was not involved with the discussion, and the user was randomly navigating or looking at a different issue, the use would be peripheral.

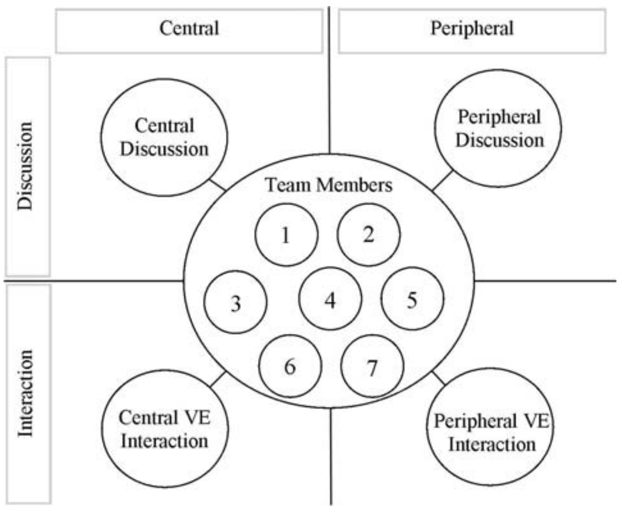

Figure 5: Tracking team member involvement in discussions

3.2 Use of virtual environments

Having identified the actions that the group has taken, the use of the VE needs to be considered to more clearly determine the role it plays in the process. The coding scheme in Table 4 will provide a simple system for tracking the information being discussed, similar in nature to that presented by Fard (2006). The columns are divided by the system being discussed, such as the shell or the mechanical system. The rows determine the form the information takes for the discussion, such as a 3D model, charted information like a schedule, or textual information such as a specification. The intent for this tracking is to determine if there are specific types of information, or building systems which are found to garner more value from the increased visualization capabilities available within a VE.

Table 3: Information format and content used in group discussions in a virtual environment (example)

	Shell/ Façade	Layout/ Geometry	Structure	Mechanical	Electrical	Plumbing	Construction
Text							
Data / Numbers							
2D Drawings							
3D Model							
Chart / Graph							
Multimedia							

Having defined the information which will be exchanged, the manner the team interacts with the information and the environment could also prove to be important. As such, the system shown in Table 4 will consider what interaction is performed and the means of interaction by the user. The VE category along the top indicates the media options available to the group. The categories could be revised to those available to the group being observed. The categories for the interactive uses, the rows, are based on the potential capabilities for using the tools, so creating a new virtual artefact would be authoring content. If the group were looking through drawings or moving through a model to identify views, they would be navigating. The analysis and simulation category would mean that they were performing calculations or editing the inputs and running an analysis during the meeting. Discussion means that the VE tool is being utilized to facilitate the conversation and would help determine which displays are found useful for different topics.

Table 4: Interaction Model with different media in the virtual environment (example)

	Paper	Input device	Laptop Display	Touch Screen	Large Screen	VE specific traits
Author						
Navigate						
Analyze Simulate						
Discuss						

3.3 Measuring Team Effectiveness

Tracking the conversation relative to the use of technology and the functions the group is pursuing will develop a clear picture of what the group is doing, and why they are doing it. It does not yet, however, demonstrate if they are being effective in their task or collaboration, or if they are using the display effectively. To track the collaborative efforts, the speakers can be tracked to see how often they speak, the number of topics they contribute to, and the amount of time they speak. This will help determine if one person is dominating the discussion, and the level of contribution from each of the members or for each of the media forms.

In addition to the input from the group members, the outcomes of the activities should also be measured. Utilizing the outcome types presented by Fard (2006): resolved, not resolved, or more information needed; the outcomes can be tracked by activity to determine the resolution rate and resolution productivity. In addition to showing the overall resolution rate, the rates can be tracked to see if the resolution rate can be correlated to the use of interactive traits, or to uses of the system.

While these shows whether or not the team completed their tasks, it does not convey the effort needed to complete a given task. The complexity and the thoroughness of a task are hard to measure, but in an effort to determine these issues, a new scale is suggested incorporating the number of individuals with input on a topic and time spent. So to determine the level of collaboration for each topic of conversation, the number of contributions to the topical thread of conversation can be counted, and the number of people having input can be used as the exponential measure, then divided by the time spent on that thread of conversation:

$$\text{Level of collaboration} = \frac{(\text{\# of contribution})^{(\text{\# of contributors})}}{(\text{time spent on thread of conversation})}$$

Along with these metrics, the incidents of conflict for the group can be tracked over time, based on the type of conflict and the stage of the process. In the study by Jehn and Mannix (2001), the potential to determine group performance was linked to the types and amounts of conflict at different points in a team’s process. For this reason the incidents of conflict will be tracked as a measure of group performance. Certain levels of process conflict, which was found to be beneficial early in the process, as well as task conflict are expected and can prove beneficial, with notation on interpersonal conflict which can be detrimental to the task performance. The manner in which these arise in setting the use of the media and how it is carried through the process should also help in longitudinal studies to show how to successfully adopt and use VEs for the duration of a project.

4. CONCLUSIONS

A framework for a new coding scheme and new metrics for tracking and evaluating team interaction in virtual environments in the AEC Industry was presented. The framework is arranged at a macro level to allow for adjustments based on the systems being utilized and the purposes of the meetings and tasks being observed. The framework also allows for the categories to be refined so more specific traits of the virtual environment, or more specific system discussions could be measured. The framework proposes the measurement of interaction based on the activities the team undertakes; the manner in which the team uses the virtual environment; the information being utilized by the team; and the outcomes of the tasks performed. In addition to tracking the actions of the team, the framework suggests tracking the continued interactions over an extended period of time, to determine long term structural traits, conflict rates, and performance outcomes.

The framework builds from the available AEC coding schemes previously used for evaluating the impact of virtual environments on team task performance. The framework must to be tested to verify its versatility in different virtual environments, and to determine scaled rates of interaction variables, conflict rates, and the newly determined metrics so they can be used to compare and predict outcomes. The framework also needs to be tested to ensure clarity of definition of the categories so that it can be used and applied consistently regardless of the researcher utilizing it. This will allow the research community to develop consistent, quantitative measures for the impact of technology of group performance within virtual environments for tasks and experiments within the construction domain.

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