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A FRAMEWORK FOR USING INTERACTIVE WORKSPACES FOR EFFECTIVE COLLABORATION

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SUMMARY: *Recent trends in collaboration within the Architecture, Engineering, and Construction (AEC) Industry have increased the emphasis on integrated project delivery, the use of intelligent models for information sharing, and the use of electronic tools for virtual teaming. While the value of these tools and methods is growing, the impact of the workspace and physical interaction of the team is often left as an afterthought. The value of the workspace, human interaction, and sense of team is not unknown, for example, face-to-face interactions are commonly emphasized in collaborative design charrettes for activities such as sustainable project design. There have been a variety of developments in improved media interface, ranging from interactive whiteboards and tablet PC's, to augmented reality and virtual reality display systems, as well as rapid prototyping. This paper focuses on bringing the physical, virtual, human, and task elements together in a framework for using interactive workspaces for more effective collaboration.*

The focus of this paper is the development of the framework for effective planning and use of interactive workspaces for collaboration. Virtual environments offer the ability to blur the lines between the physical and virtual, interactive workspaces are a subset of virtual environments where the physical spaces allow ubiquitous and intuitive interactions with the virtual content. The framework describes how the virtual and physical technologies relate to team collaboration. The background and development of this framework are presented with a focus on face-to-face collaboration in interactive workspaces (IW). To demonstrate the use of the framework, a series of 24 undergraduate student teams in the architectural engineering program at Penn State were studied using four different configurations of an IW at Penn State. The study of the students identifies the aspects of the IW framework which influence the team interaction based on the task, and using observational studies tracked interactions among individuals and with the media interface to compare differences in use and outcomes between media modalities. Outcomes indicate measurable differences in the individual contributions to the discussion and through the interface based on the configurations used. The paper concludes with the value of employing the framework for comprehensive planning of collaborative efforts.

KEYWORDS: *interactive workspace, observational study, media modality, framework development.*

REFERENCE: *Leicht R M, Messner J I, Anumba C J (2009) A framework for using interactive workspaces for effective collaboration, Journal of Information Technology in Construction (ITcon), Vol. 14, Special Issue Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning, pg. 180-203, http://www.itcon.org/2009/15*

1. INTRODUCTION

The introduction of the cellular phone has created a drastic change in the time and place of both personal communication and business discussions, just as the Nintendo Wii® has transformed the way people play video games. And while movies such as James Bond, Minority Report, and Star Trek paint very futuristic pictures of how people will use computers, many of the modes of interaction from touch screens, to voice commands, and further to some of the gesture interpretable interactions, are being researched though not yet commercially available or with limited industry adoption. While these movies at times may seem far-fetched, the technology is within the reach, and in many cases is being currently researched or developed. As these tools become more readily available, they will greatly influence the time, place, and manner of interaction with digital information.

The pace of technology development creates an ever-changing landscape for personal interaction and the versatility of tools is constantly changing the "best practices" for many industries. With the Architecture, Engineering, and Construction (AEC) Industry constituting one of the largest business sectors in most developed countries, and an even larger percentage in rapidly developing nations, the industry needs to be able to enable and improve business practices through the use of these new methods and new technology, without adversely affecting company culture, relationships, or the bottom line. As ubiquitous and pervasive computing begins to further enable more intuitive interaction and more fluid sharing of information, firms will need to plan how they will take advantage of these new media tools. Firms may be able to move into new modes of virtual teaming with the sharing of information amongst disciplines becoming more seamless, but the overlap of discipline decisions will require tighter integration and collaboration encouraging new delivery methods on capital projects. All of these concepts are possible, but firms need to understand where they want to position their business within this new landscape and identify which tools and processes they want to pursue. This paper introduces a framework for planning interactive workspace infrastructure by identifying the fundamental components and considerations when performing collaborative tasks so a project team can plan what means of interaction and information sharing to utilize on projects. With the increasing complexity incorporated into buildings along with the fragmentation and specialization which has occurred over the past 100 years, collaboration and teamwork have been an ongoing challenge (Magent, 2005). More recent changes in the technical systems used, widening global networks, and advances in technology have only made this challenge more complex. While widening availability of information and communication technology (ICT) tools creates greater resource availability and faster communication, they also are constantly changing and add another level of concern when solving problems or developing designs. Through recent emphasis on building information models and integrated delivery of projects, there has been a need for better collaboration. With the inter-organizational teams, changing dynamics, and challenging projects, collaboration and information exchange is essential to successful projects. To these ends, a framework was developed to demonstrate the links between collaborative tasks which take place on facilities projects and the physical and virtual tools. This framework allows for companies or project teams to identify the tasks they undertake in a collaborative manner and determine the characteristics of the communication media which most impact the processes taking place. The team can then plan the modes of interaction which best complement the processes and tasks being used. Beginning with the background of the study which motivated the development of this framework, this paper then presents the research from social psychology and communications that allow for collaboration to be related to technology in AEC applications. A study in the application of the framework using an undergraduate site planning task is then used to demonstrate the use, followed by conclusions about the use and value of the framework.

2. BACKGROUND AND DEVELOPMENT

The development of the framework for utilizing interactive workspaces is the result of an ongoing study of the media forms and modalities for design and construction. It is necessary, therefore, to provide some context, background work, and findings that have shaped and focused this effort. After providing the context of this study, the explanation of the framework and its development are presented. The testing and validation of this framework is an ongoing effort, limiting demonstration of the full array of application and robustness to a particular application. The application of the framework employed a quasi-experiment to compare outcomes among 24 student teams utilizing an interactive workspace for a collaborative design task. The results of the quasi-experiment are used to demonstrate the applicability of the framework to other scenarios, tasks, and teams.

2.1 Modes of ICT use

The recent popularity of building information models (BIM) can in part be attributed to their versatility in conveying the type of complex information common to AEC tasks. Along with this versatility, the popularity has also coincided with developments in computing technology to allow real time viewing and interaction of the BIM (Tse et al, 2005). This complementary development of hardware and software capabilities points to the importance of the relationship between the form of information and the modality of transmission.

Much research relating to BIM and electronic data references to the value of the physical displays and modes of media interaction. Khanzode et al (2008) identify added value of the Obaya, or big room, in which the 3D MEP coordination took place at the Camino Medical Center. The coordinators developed their shop drawings as a collaborative effort, working as an interdisciplinary team in the Obaya for the duration of the coordination efforts. Liston indicates value of a large scale display to the communication process when using 4D technology in construction project progress meetings (Liston, 2001). Fruchter (2005) identified differing levels of engagement in a remote presentation and discussion amongst students and industry presenters when using the FISHBOWL facility at Stanford. Findings indicated that remote viewers may actually have a higher engagement level because of the displays they employ. These examples show the relationship between the requirements of physical media modes and the interaction for collaborative purposes in AEC tasks.

While some work has come across the implications of modes of interaction, there has been significant work in the facility design and construction field focused on studying specific applications of media displays and interactions. Maldovan used an immersive display to host a virtual mock-up in the review of a federal courtroom design (Maldovan et al, 2006). In an extensive study of the relationships between model detail and display traits, Zikic and Nikolic performed an in depth study of student's understanding of space, perception, and understanding of building layouts utilizing several different immersive display configurations. The results indicate differing relationships depending on the detail in the model and focus of the use, but that clear relationships can be drawn between the model and the display traits as they affect perception and understanding (Zikic, 2007; Nikolic, 2006). These detailed studies of the application of specific media to AEC tasks show the importance of individual media traits when focusing on a specific task and objective.

Along with work focusing on the perceptions of displayed information or the relationship of the information t the display, recent work has begun to focus on how teams of people interact with the information and display. Leicht et al (2008) found the stages of problem solving which industry members considered the most important for collaboration, were the same stages where teams identified interacting with display or physical media as being the most valuable. Issa et al (2007) identified greater perceived efficiency by students when utilizing and interactive workspace for a capstone design project. With more information stored and documented electronically, the ability to more easily and intuitively interact with electronic information is going to become essential in teamwork and collaborative efforts. The challenge is to find a means for planning this media use to best serve facility needs.

2.2 Exploratory Study

To further study the impact of physical media and the potential large scale implications an exploratory study was undertaken. The study considered the rapid pace of BIM development and use in the Scandinavian countries (Fox and Hietanen, 2007) and focused on AEC firms in Finland to identify how implementation of BIM usage translated into new media uses, modalities, and needs. The main findings of the study indicated that while BIM was found quite valuable particularly for collaborative efforts, the collaborative value was not being realized in an inter-organizational context. From the interviews carried out it was also found that collaborative activities, even when using BIM, were still believed to be more effective in face-to-face communication. Changes commonly found over the three year period studied were the shift to using two or three screen desktop displays, the incorporation of large scale conference room display systems, and in some cases the use of interactive displays, such as interactive whiteboards. Despite a perceived impact by physical media, all of the companies studied continued to approach the physical displays as a secondary consideration.

2.3 Research strategy

To carry forward these insights a research plan was implemented with the refined research focused on interactive workspaces, as shown in FIG. 1. Following the exploratory study, the framework development started and was quickly paralleled by the validation method work. Following these, the framework was tested in the preparation of a longitudinal study. To properly develop the framework, current theory was utilized to build relationships amongst the elements involved in both collaboration and AEC tasks using the following steps:

1. Identify a consistent set of collaborative objectives and tasks
2. Develop links between AEC tasks and the prescribed process of "collaborating"
3. Explore collaboration to identify media factors which relate to successful sharing of information
4. Map these factors to media traits which can allow for planning of interactive workspaces

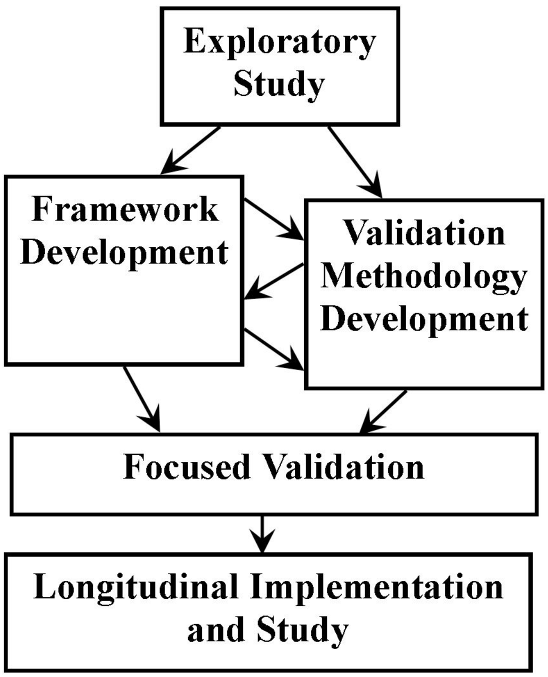

FIG. 1: Interactive Workspace Research Strategy.

Concurrently with the development of the overall framework, work was being carried out to find and customize a research method that would allow for verification and validation of the framework in use. The framework brings together several elements, each of which has its own challenges. To analyze all of these elements, observational studies were chosen. The ability to observe each element and through content analysis perform rigorous study is commonly used in the social sciences where complex relationships involving human variables are studied. Within this observational methodology a coding schema was created to analyze the content of team interactions within interactive workspaces. The coding schema was developed in parallel with the overall framework, allowing for cross testing and ensuring that the coding would allow for evaluation of the framework.

As the framework neared completion, it was essential that testing and validation began. To these ends an undergraduate engineering class at Penn State performed the conceptual design of their site utilization plans in the Immersive Construction Lab (Icon Lab), shown in FIG. 2. A series of 24 teams used the lab as part of a semester long project. Each of the teams was video-taped while in the ICon Lab allowing for observation and detailed content analysis using the developed coding schema. This allowed for a single application of the framework to be evaluated. While this does not validate the entire framework, it demonstrates the ability to evaluate each piece, and the applicability to task planning.

FIG. 2: Image of the Immersive Construction Lab at Penn State University.

3. FRAMEWORK

The preliminary work performed identified four components which come together in the use of interactive workspaces as the starting point for developing the framework:

1. AEC tasks
2. Means of collaborating to meet the task objectives,
3. Fundamental communication factors, and
4. Interactive workspace traits.

The role each plays will briefly be introduced both for its individual impact and as it relates to the framework and use of interactive workspaces.

3.1 Identifying AEC Task Objectives

In order to develop a framework for planning the use of interactive workspaces for different AEC tasks, it was first necessary to identify the tasks and their objectives. There were a few simple requirements to identify these tasks: they should be interdisciplinary in nature, they should be collaborative tasks, and they should have a clear objective or outcome. To identify these tasks and their objectives, the Integrated Building Process Model (IBPM) was utilized. The IBPM was developed to identify the processes needed for planning the delivery of an integrated building project, as shown in the sample in FIG. 3 (Sanvido, 1990). In conjunction with this process model, a Process Based Information Architecture was developed to define the information needed to plan, design, construct, and operate a facility (Sanvido et al, 1995).

This process model of facilities planning and implementation was used because it considers a project throughout its lifecycle, it shows the players involved in each step, it identifies the resources and deliverables, and it considers projects from an integrated delivery perspective. Also, over the past 20 years since its development, it is still relied upon in process and delivery method research in facilities as a key resource whether studying anything involved in the integrated delivery of buildings, from high performance building delivery (Magent, 2005) to lean and transparent processes (Klotz, 2008).

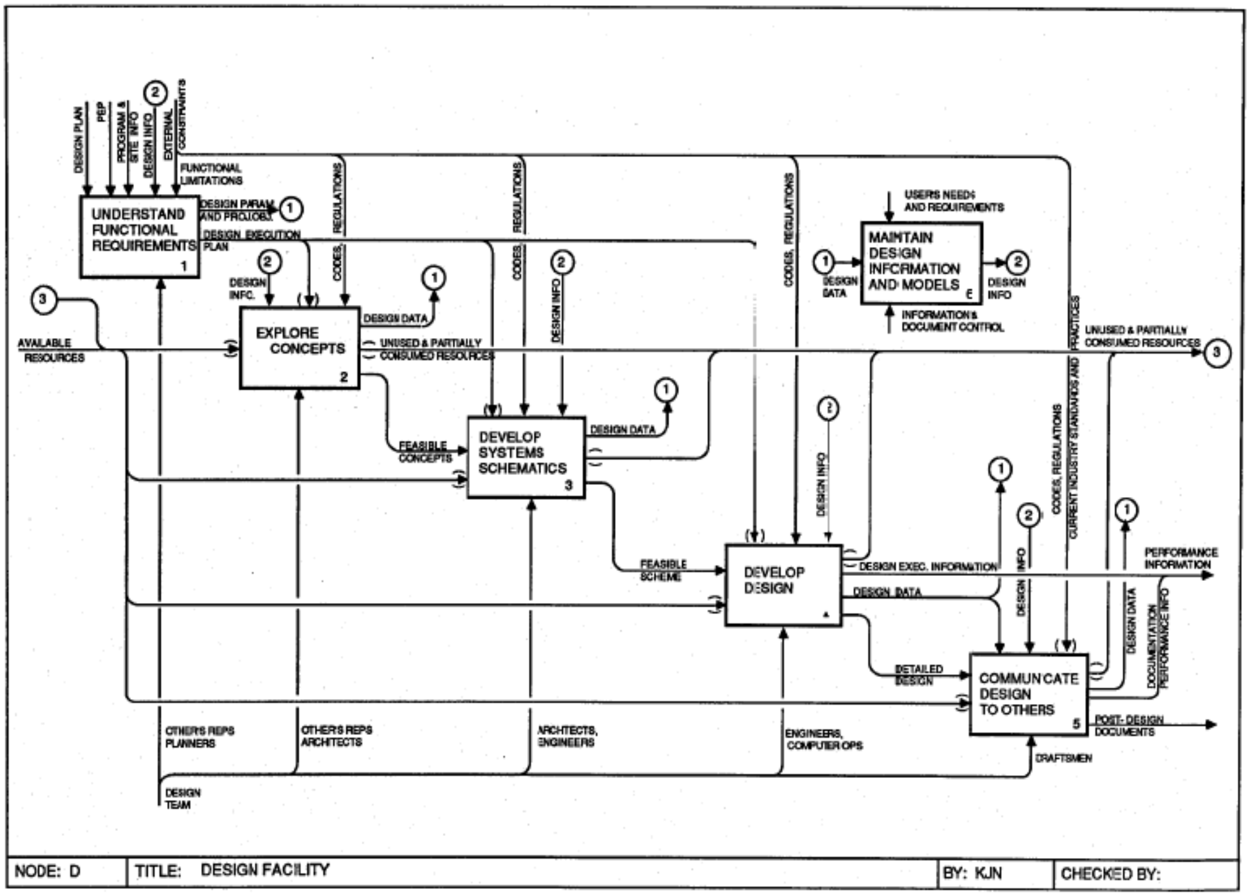

FIG. 3: Section of the Integrated Building Process Model using the IDEF0 Modeling method (Sanvido, 1990).

To develop a common set of collaborative task objectives from the IBPM, the steps of the design and construction phases were used to identify interdisciplinary project steps. Since the IBPM was developed using the IDEF0 modeling method, the resources and mechanisms for each step are clearly identified and any step with multiple disciplines indicates the need for collaborative efforts amongst those disciplines. From this narrowed list of project steps, the tasks were sorted by the deliverables, or outputs. The reason for using the output to sort the steps is that objectives serve as measurable sub-goals, with the output as the means to evaluate those sub-goals. Tasks with similar objectives were evaluated based on similar outputs, as sample of which are shown in Table 1.

Table 1: Sample of IBPM Tasks, Disciplines, and Outputs.

Cell #	Task	Disciplines	Outputs
D21	Perform preliminary studies	Architects, Engineers	Design data (spatial relationships, site use, etc.)
D22	Prepare and develop concepts	Architects, Engineers	Concept informationdata, possible concepts
D23	Coordinate concepts	Architects, Engineers	Compatible concepts
D24	Evaluate and select concepts	Architects, Engineers	Feasible concepts

From these sorted tasks and outputs, four common over-arching objectives were defined:

1. *Create design content*: Authoring, expanding, refining, and identifying information and constraints which advance the development of the building concept with increasing level of detail as the concept evolves.
2. *Integrate design content*: Combining information from design subtasks and ensuring the extent of compatibility amongst the compiled concepts and systems.

3. *Examine design content*: Reviewing the design for viability and to ensure compliance with the design goals and intent.
4. *Focus design content*: Identifying the concept(s) which best satisfy design requirements and offer the opportunity for advancing the project.

These defined objectives show the purpose of the collaborative acts amongst team members, but in order to utilize interactive spaces effectively, the manner of collaboration needs to be more clearly identified.

3.2 AEC tasks to Collaborative functions

Since the manner of collaboration is not explicitly defined within the IBPM, it was necessary to identify another source for how teams can combine their efforts to reach a given objective. Ivan Steiner, a social psychologist, compiled one of the defining works on team collaboration. In his work, Steiner demonstrates the two fundamental means of combining individual efforts, with two types of outcomes for those efforts (Steiner, 1972). In FIG. 4, a matrix showing the four means of matching these variable breaks the concepts down into four options. The two options for combining efforts are unitary efforts and divisible efforts. Divisible efforts consist of tasks which can be subdivided and team members can separate to make individual contributions, that when brought back together combine to make the overall team's contribution. For example, if a group of people were to work on a set of a dozen math problems, the team could assign each member to certain problems. On the other hand, a unitary effort is one in which the individual efforts cannot be subdivided. So if that same team were to work on solving a riddle rather than a set of math problems, they would be unable to divide the riddle into pieces and have members solve each piece. The riddle needs to be taken as a whole with the team contributing to a shared solution.

Means of Combining Team Efforts

		Unitary	**Divisible**
Process Outcomes	**Optimizing**	Unitary Optimizing	Divisible Optimizing
	Maximizing	Unitary Maximizing	Divisible Maximizing

FIG. 4: Matrix of combining team efforts based on work by Ivan Steiner (1972).

The matrix is also divided by the outcomes of the teams' efforts. The two terms used, maximizing and optimizing, may be slightly misleading. The terms apply to describing the process of combining the team's efforts rather than to the process of solving a problem. So an optimized outcome would imply one with a very thorough analysis to reach the most effective solution, such as studying a building's energy use to optimize the use of energy; in this case it is referring to how efficiently and effectively the team spends their time and energy in solving the problem. The term is intended to mean the team combines their efforts effectively to meet a preset standard, rather than coming up with a best answer. In comparison, the maximizing outcome is one in which the team explores the full extent or potential output of their efforts, rather than stopping when they hit a pre-determined point. So referring again to the building energy example, the effort would be optimizing if the team were trying to get the building to a set energy level, but maximizing if they were trying to obtain the most efficient energy usage.

When identifying the objectives from the IBPM, one of the first requirements of the tasks was that they were collaborative in nature. Reviewing Steiner's defined team efforts, divisible tasks are by definition not collaborative. It is only the unitary tasks which would be valuable in meeting collaborative objectives. To these ends, the use of the matrix is narrowed to the two cells under the unitary efforts. By comparing the objectives from the IBPM with the two outcomes from team efforts allows for demonstration of the relationships, as shown in FIG. 5.

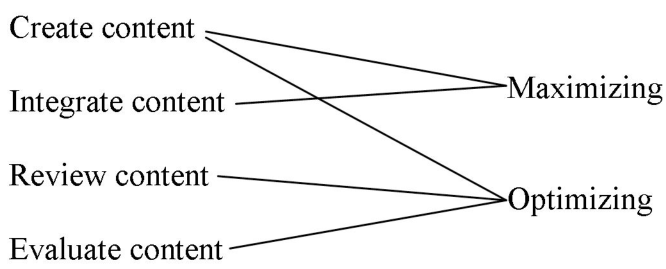

FIG. 5: Map of AEC task objectives to collaborative outcomes.

For both of the defined outcomes, maximizing and optimizing, Steiner moves on to define prescribed processes for how teams are able to combine their efforts to meet their stated outcomes. For an optimizing task there are two possible means of bringing together efforts, either a discretionary or disjunctive manner must be used. For discretionary tasks, the team has the ability to weight the input from each team member to reach an outcome which pulls together the knowledge and abilities of the team. For example, if a team were trying to estimate the temperature in a room, the team could average the individual guesses or weight input from each member by some algorithm. For a disjunctive task, like the riddle mentioned earlier, there is no means to combine answers but a single answer must be given the total weight of the team's effort. In some, but not all cases, this can come in the form of an epiphany or "eureka" moment when a team member comprehends the answer. These are the two means available for teams to combine efforts in meeting the outcome of an optimizing task.

For maximizing tasks, there are two different opportunities available for combining team members' efforts. One means of combining efforts is in an additive manner. In additive tasks the contributions of each team member are summed to find the whole team contribution. For example, if the team is holding a brainstorming session, the total possible ideas contributed are determined by adding all of the individual ideas from the team members. The other manner for combining in a maximizing task is in a conjunctive way. In conjunctive tasks the team is limited by the weakest link. For example, the way an assembly line can output only at the rate of its slowest step or a string of mountain climbers can only move as fast as the slowest member. In problem solving tasks, this usually falls to the team member whose input is necessary to solve the task but is having the most trouble in comprehending the problem or the information they need to contribute to complete the puzzle. These efforts prescribe the processes for combining efforts in a maximizing task.

With these means and prescribed processes for bringing together team members' efforts, the start of the framework and planning was created. In *Table 2* the steps of the design and construction process are linked to show the output, objective, outcome, and prescribed process(es). This is the initial relationship which was built upon to identify the necessary infrastructure in an interactive workspace to facilitate effective collaboration.

Table 2: First step of framework of AEC Tasks developed to relate means of collaboration and prescribed processes.

	Phase / Stage	Unitary/ Divisible	Objec-tive	Level of Detail	Opt / Max	Add/Disj/ Conj/Disc
D	**Design Facility**					
D1	**Understand Functional Requirements**			Conceptual		
D11	Assimilate and analyze information	Unitary	Focus	Conceptual	Opt	Disj or Disc
D12	Establish project objectives	Unitary	Create	Conceptual	Max	Add or Conj
D13	Establish design parameters	Unitary	Create	Conceptual	Max	Add or Conj
D2	**Explore concepts**			Schematic		
D21	Perform preliminary studies	Unitary	Create	Conceptual	Max	Add or Conj
D22	Prepare and develop concepts	Unitary	integrate	Schematic	Max	Add or Conj
D23	Coordinate concepts	Unitary	Examine	Schematic	Opt	Disj or Disc
D24	Evaluate and select concepts	Unitary	Focus	Schematic	Opt	Disj or Disc

D 1 – Design Task 1 D11 – Sub-task to Design task 1	Opt – Optimizing Task Max – Maximizing Task	Add–Additive Disj-Disjunctive	Conj–Conjunctive Disc-Discretionary

3.3 Collaborative functions relating to Communication Theory variables

While using Steiner's work helps to understand the means of combining individual efforts and the processes, it still is lacking the elemental details of the information sharing which is necessary to define the use of artifacts and interfaces within an interactive workspace. As team members work together to achieve the defined objectives and tasks, they will move through many communicative acts and the documentation of project information. As team discussions take place, there are five fundamental factors for any communicated information which influence how it is transmitted from one person, through the available medium, and the richness with which another person receives it, as shown in FIG. 6.

In traditional communication theory there are a few key elements in any act of communicating a message between people. Within the facilities industry these acts and messages often involve complex problems and not one but multiple project stakeholders and team members. With the complex and multimodal forms of information being used, the form of the information conveyed and the mode of transmission of the message play a greater than usual role in the team reaching a shared understanding of the problem.

Media Synchronicity Theory (MST) relies on the variables presented in FIG. 6. These variables are:

- Feedback Immediacy – the variable defining the rapidity or latency of the return communication provided upon receiving a message
- Symbol Variety – the forms and perceptions which can be utilized to pass information
- Parallelism – number of channels upon which information is transferred
- Rehearsability – time and ability to refine a message before it is transmitted
- Reprocessability – time and ability to review and deliberate upon a transmitted message

In MST there are two underlying processes related to sharing and understanding communicated information and the thought process: conveyance and convergence. Conveyance is focused on providing information for deliberation, while convergence relates to the development of a shared understanding. Depending on the focus of the communicative act, the five fundamental factors shown in the model in FIG. 6 vary in value depending on whether the intent is conveyance or convergence (Dennis et al, 2008). Along with the process, the context and team's experience with each other also affects the transmission of the information.

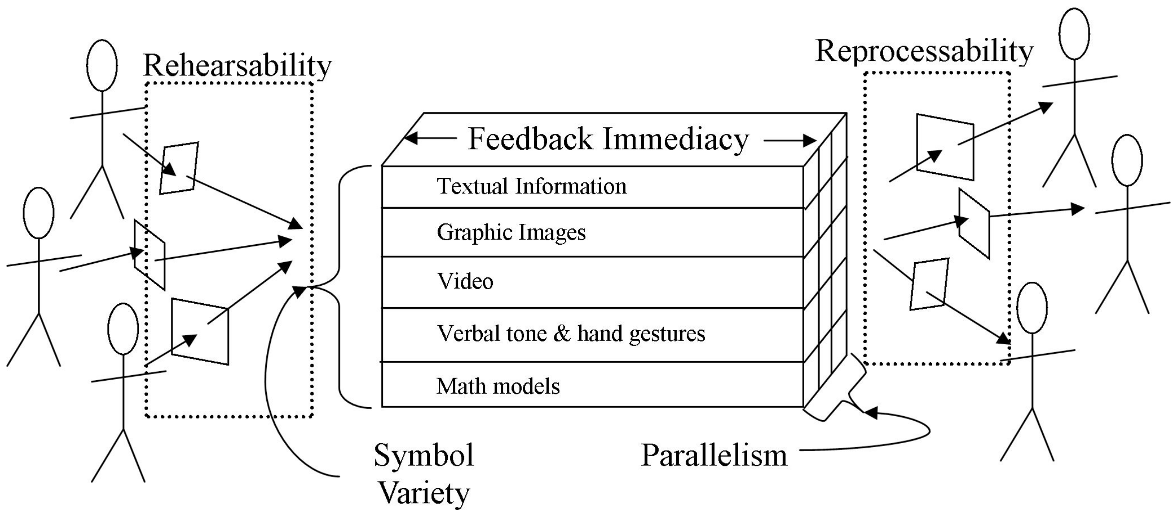

FIG. 6: Media Synchronicity model of media capabilities visually demonstrating the 5 defined fundamental capabilities of media in the communication process, adapted from Dennis et al (2008).

Considering the context of teams working on a collaborative task for a facility, some of these variables are already narrowed or defined. In a collaborative meeting the rehearsability and immediacy of feedback are narrowed to relatively immediate feedback and limited rehearsability, with the exception of information prepared before the meeting. There will be limited rehearsability and relatively immediate feedback amongst the team members for almost every exchange of information. With the narrowed factors to those which have high variability, considerations can mostly focus upon symbol variety, reprocessability, and parallelism when determining which media traits are most valuable or effective for facilitating collaboration.

Most tasks within the identified AEC collaborative tasks defined in the IBPM focus on the convergence of team understanding needed to move forward with decision making. The use of conveyance is for transferring information and allows team members to digest and deliberate on what they have learned. In most collaborative efforts the focus is getting to the decisions which affect the task objective. However, conveyance and convergence are not mutually exclusive; they fit within a spectrum with a balance depending on the amount of information to be deliberated upon and the challenge of reaching mutual understanding. Comparing these two underlying processes to the collaborative functions reveals that conveyance is more important in tasks with maximizing means of combining team efforts. Optimizing tasks, conversely, benefit more from media which facilitate convergence. This is not stating that both communication processes are not needed for both collaborative outcomes. In relative terms, as indicated in FIG. 7, optimizing tasks are more convergence focused than maximizing tasks.

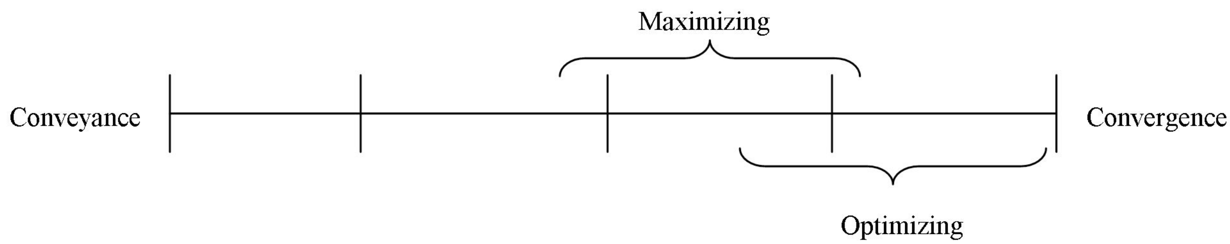

FIG. 7: Continuum of Conveyance and Convergence showing relationship to collaborative outcomes.

Having identified the relative importance of convergence and conveyance allows for the selection of the MST capabilities which have stronger correlation to conveyance and convergence processes. MST defines processes which benefit more from convergence as high synchronicity and conveyance as low synchronicity. High synchronicity communication benefits from higher levels of feedback immediacy, low levels of parallelism, and lower or as needed levels of reprocessability. Both conveyance and convergence benefit from higher rehearsability; however there is an inverse correlation between high rehearsibility and high immediacy of feedback. Simply put, if someone takes longer to craft a refined, return message, it takes longer from when they receive it to when they send it. Symbol variety is somewhat unique because it does not vary as high or low, but is based on whether the needed symbol to properly communicate the message is utilized. Each factor has a role in the communication of information and will need to be considered for each objective.

Upon further study, it is clear that none of these variables are independent, but each factor is linked to the others. Therefore, as each is planned for the application to interactive workspaces, the impacts on the others needs to be considered. When moving from understanding the implications of media factors to planning the modalities of interaction this becomes essential. For example, if a team is going to be utilizing a 3D model for review of a design, the 3D model dictates the symbol to be used, but it in turn relates to the need for a shared display of sufficient size to allow the team to all be able to view the model, which will affect the immediacy of feedback of how quickly team members will be able to see and understand the design. The ability to view the model will also affect the reprocessability of the content. Along with being able to view the 3D model, the team will likely want to navigate the model to see different views, influencing the parallelism through the ability to both view and interact with the model. Thus each trait that is defined begins to narrow the field for the other factors and all will need to be planned for effective use.

3.4 Planning Interactive Workspace Characteristics

Before planning the use of an interactive workspace, it is first necessary to understand the common components to be planned to cover the full array of planning needs. The traits are identified in FIG. 8, and match those defined by Rankin et al (2006).

3.4.1 Defining Interactive Workspace Characteristics

Just as MST has five factors affecting communication, interactive workspaces also have five fundamental characteristics which can vary in implementation and value. As shown in FIG. 8 the five characteristics are:

- Artifacts,
- Display systems,
- Interactive systems,
- Access, and
- Workspace architecture.

The first characteristic, and driving force for the need for interactive workspaces, is the artifacts to be viewed and utilized. In current practice, virtual artifacts likely consist of BIM, electronic CAD files, or possibly electronic sketching tools. The potential for physical artifacts needs to be considered as well. The industry still relies mainly on paper drawings, and some physical models, due to their versatility and clearly defined status in contract documents. These tools are not without value and will likely continue in some capacity. Along with the consideration of the makeup of the file, the form of the information, whether linguistic such as contracts, analog such as a 2D drawing or 3D model, or arbitrary like sketched concepts, play a role in the use of the content.

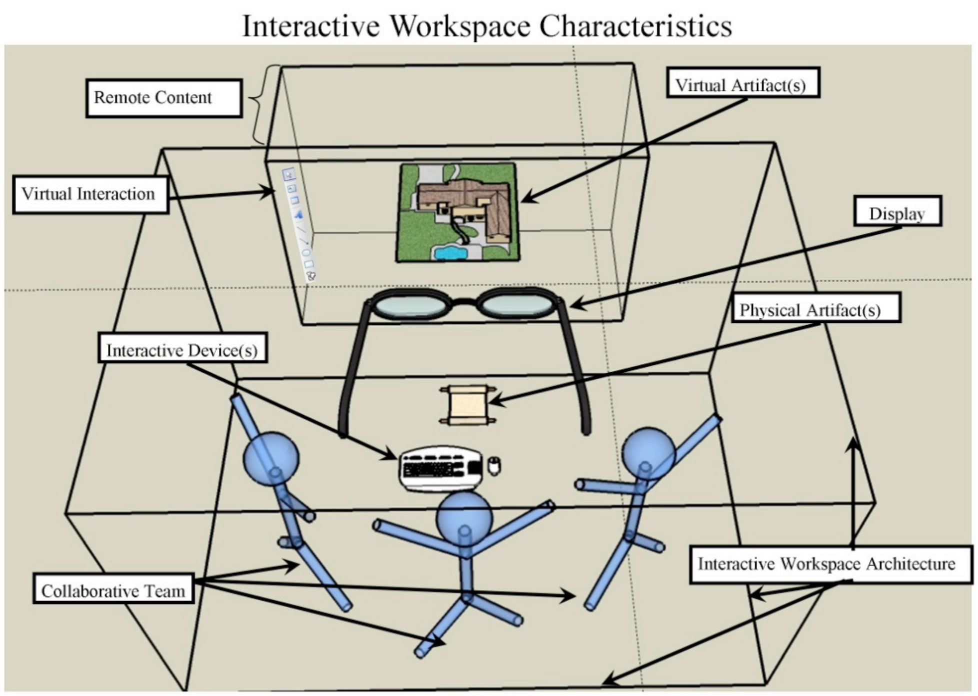

FIG. 8: Diagram of interactive workspace components, refined from Leicht et al (2007).

As electronic artifacts serve as one of the primary drivers, the display system is critical as a means of viewing this content. While display implies a visual means of reviewing content, the artifacts may provide visual, audio, or even haptic feedback to users (Bernsen, 1997). It is theoretically possible to provide feedback in the form of smell or taste, however, the application to the building industry is limited and the current development such tools is too preliminary to consider as adding value in planning interactive workspaces. Planning the display requires consideration of the number of shared and individual display systems, the scale, resolution, and field of view of each visual display, the value of stereo capabilities, and the resolution of the information feed. This component is the information and content which serves as the documentation of both previous efforts and outcomes of each meeting and task.

Just as display implies visual feedback, interaction often puts into mind a keyboard and mouse, as shown in FIG. 8. The potential means of interaction is not limited to these two devices. There are a range of interactions, both device mediated or touch sensitive. The planning of the interaction can influence both the ease or difficulty of the task. Some recent research into multimodal interaction has shown that when people are involved with more complex problems, switching to the use of more than one mode of interaction can spread someone's cognitive load to other areas of the brain and let them focus on the issue more effectively (Oviatt et al, 2004). Recent work in smart spaces demonstrates the capabilities for identifying specific signals and gestures for extending the means of interaction (Zhang et al., 2005). Some of the considerations for types of interaction include the use of tracking, whether for a specific device or through gesture and video, the use of cameras and microphones to capture and document or distribute interaction activities. There is also the potential for having either individual or simultaneous interaction with the system.

The considerations of the interaction and video capture naturally leads to the ability to interact with remote information and remote team members. The ability to access content outside of the infrastructure within the interactive workspace will enable teams to utilize the space more readily, they will not need to plan each and every piece of information which needs to be transported to the room and loaded onto the system. Along with the access to remote information is the ability to interact with remote team members. Virtual teaming and computer mediated communication is growing in use and one of the array of valuable activities for which an interactive workspace could be used. The considerations for access would include planning which displays would need to be shared, infrastructure and firewall issues, and what type of direct communication will be employed, such as video-conferencing, teleconferencing, a virtual meeting space using avatars, or instant messaging tools. Planning for access increases the value of the workspace and the ease with which different teams and personnel from different companies can come into the space and become involved and engaged in the process, whether there physically or virtually.

The last component to consider when planning for the use of an interactive workspace is the physical architecture of the space. The shape, layout, and physical items, such as furniture, influence the comfort level and ability to utilize the space from the human perspective. The use of different layouts and configurations will be conducive to different size teams, different tasks and enable viewing of the different physical media in the space. With the use of the electronic infrastructure required in an interactive workspace, the lighting, data, and HVAC systems also need to be planned to support the work and comfort of the teams. Teams will quickly be discouraged if the lighting levels strain their eyes or if the temperature and humidity of a space are uncomfortable. The layout and configuration influence how the individual team members will be able to interact with each other, discuss information, or be able to utilize the physical media available in the space.

These five characteristic areas provide the basis for planning an interactive workspace and its use. Each of these components is linked to the factors influencing communication, and thus they need to be planned to best facilitate the overall communication process which takes place within. Planning the characteristics brings together all of the steps demonstrated thus far.

3.4.2 Planning Interactive Workspace Characteristics

Having identified the tasks in the design and construction process and carried those through to the traits which can be planning in an interactive workspace, the steps for planning need to be defined. The process follows these steps for developing the framework, demonstrated in FIG 9.

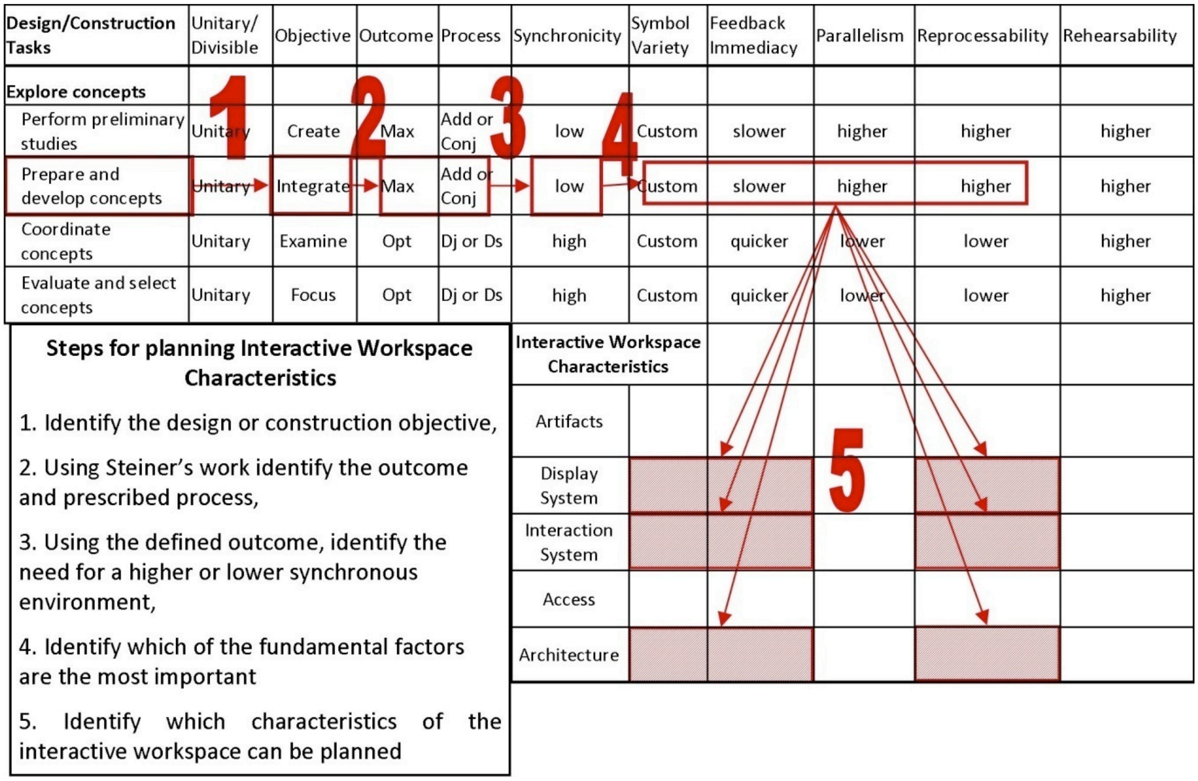

FIG 9: Diagram showing the steps of identifying the focused planning characteristics for an Interactive Workspace.

While the diagram shows the steps and the components could be explained in great detail, diving directly into an example of the use of this framework in the context of the study will better demonstrate the relationships and implementation.

4. DESIGN TASK VALIDATION

Having developed the framework, testing the application of the framework to an AEC task and testing implied outcomes is essential to evaluating its value. To these ends a quasi-experiment was undertaken to evaluate the application within a single task. The quasi-experiment consisted of 24 teams completing a single schematic site utilization planning task in the ICon Lab at Penn State. The teams were videotaped and the tapes were analyzed to identify differences in the use of the infrastructure and behaviour of the teams while they were completing their task. In addition, a post-test questionnaire was distributed to the teams to identify the perceptions of the use of the interactive workspace while completing the assigned task.

4.1 Quasi-Experiment Design

Due to the lack of control of all aspects of the study, a true experiment is not possible. The challenge in using a true experiment for this study is in demonstrating that the teams would have met equivalent outcomes if not given the treatment (Campbell and Stanley, 1963). The teams for this quasi-experiment were pulled from a third year undergraduate course in architectural engineering with 95 students randomly divided into 24 teams of three or four members. The teams were as homogenous as could be expected for a study of this type with all participants of similar standing, coursework, and industry experience. The teams were consistently used throughout the spring semester of 2008, with the quasi-experiment falling 11 weeks into the semester, nearing the deadline of their second project submission.

The teams were tasked with developing site utilization plans for a project for which they were developing an estimate and schedule. Since this was their first introduction to site planning, the task provided clear direction and the activity in the ICon Lab asked the students to focus on developing the schematic layouts for three defined phases of the project: substructure, structure, and enclosure of the building. In order to complete the task, the students were randomly assigned to one of four configurations of the ICon Lab. The configurations relied upon two variables; the type of interaction the students had with the computer and the availability of the 3D model. The work in the task being performed by the teams in the ICon lab is in the first subtask for developing a construction plan from the IBPM, where the teams determine the scope of work and coordinate planning for the site. The level of detail for the task is schematic in nature, and the objective is to create the site utilization schematic. The activity can be identified as a maximizing task and will benefit from slightly more conveyance oriented influences. With the task requiring a less synchronous environment, slightly less immediate feedback, higher parallelism and higher reprocessability will be beneficial, and it needs to include appropriate symbol variety.

Table 3: Summary of considerations for MST Fundamental factors by IW traits.

	Content	Display	Interaction	Remote Access	Layout
Symbol Variety	2D or 3D content	Scale large enough for group	Ability to sketch and write	If remotely viewing, appropriate form of info	Ease of access to various symbols
Reprocessability	Persistence of options or notes	Persistence of confirmed data on shared display	n/a	Persistent shared remote display/ documentation	Persistent view of shared information
Parallelism	Ability to show options/explore ideas	Several displays	Ability to sketch different options	Multiple feeds/ screens shared	Ability to view others work, share own work
Rehearsability	Some time to deliberate on idea before providing feedback	Option of hiding and showing content under development	Can develop and revise content before sharing	Time to prep message before sharing	Privacy to develop and refine content
Feedback Immediacy	Ability to choose when to share information	Easy viewing of information for comment	Ability to write/ sketch on display	Manner of feedback (conference call, shared sketch)	Ease of discussing with other team members/ facing each other or display

In developing a study to test the validity of these concerns, the study focused on a face to face meeting of teams, thus remote access considerations were not taken into account. Since the focus of the study was concerned primarily with the physical media traits, the layout of the space for each of the four configurations is consistent, within the bounds necessary for the uses employed, thus narrowing the variables to content, display, and interaction. The teams were given a consistent form of interaction based on the considerations that sketching will most likely be the most valuable interaction for a schematic design activity. As shown in **Error! Reference source not found.** the two cells selected as the focus are the option of having one or several displays, and 2D vs. 3D content. This also suggests that there may some variance in the parallelism of the content and interaction seen, and possibly some variation in the display symbol variety and interaction symbol variety.

4.2 ICon Lab Configurations

Utilizing the framework, the teams were divided into four treatments with six teams randomly chosen for each of the four treatments. The building site was inserted onto a PowerPoint slide, allowing the students the ability to sketch on the slide, and take the output out of the lab with minimal concern for software and file concerns. The PowerPoint file had four slides, one for each of the three required site phases, and a blank slide for taking notes. Twelve of the teams used tablet PC's and the other twelve worked using a single interactive whiteboard. Of the twelve using the tablets, half were given an extra laptop with a 3D model of the building which the students had already used in a previous assignment, the other half were only given the PowerPoint slides. The same was done with the interactive whiteboard, with six teams having access to the 3D model, and six without.

In layout I, as shown in FIG. 10, the teams were provided with a tablet PC for each member, with an extra laptop PC showing the 3D model of the building. They began with two of the tablets linked to two of the large screens, and the third screen showing the 3D model. The team members had the ability at any time to change which PC was displayed on any of the three screens. This layout should have provided high parallelism for the team to interact with the display, high reprocessability for the images which can be re-shown from different tablets and high and flexible symbol variety with the sketching capabilities and the use of the 3D model.

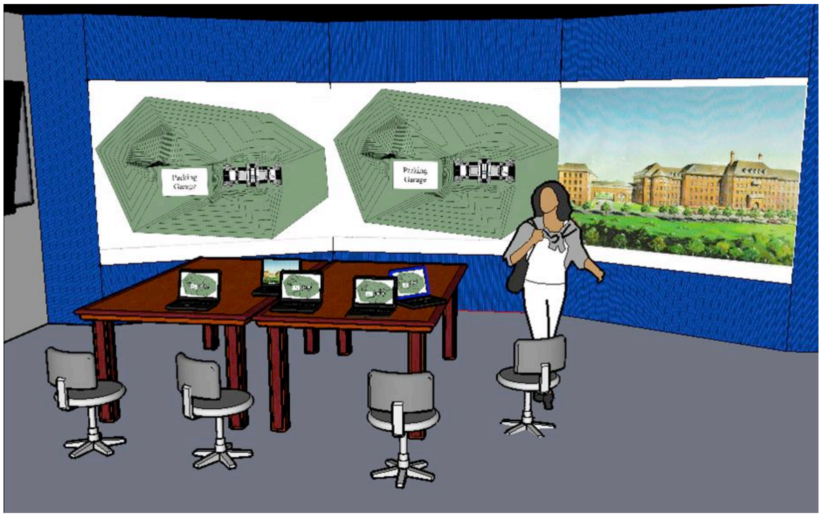

FIG. 10: Layout I: Three screen displays linked to the PC's shown, the three screen images can be interchanged with any of the PC's.

In layout II, as shown in FIG. 11, the teams were again provided with a tablet PC for each member. However, the spare PC with the 3D model was not provided to the team. The task began with each of the three large screens having a different tablet PC linked. Again, the team had the ability to change which image was being displayed at any time throughout the task. This layout should have provided high parallelism for the team with the use of the tablets, high reprocessability regarding the ability to change the images on the screens, and high and flexible symbol variety with the sketching capabilities. The symbol variety would be lower and less flexible than layout I due to the reliance on only a 2D visual of the site, rather than having the 3D model available.

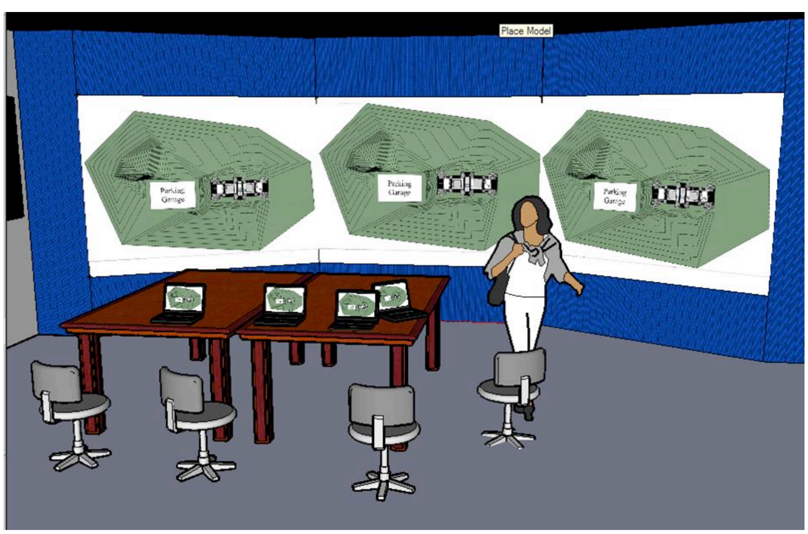

FIG. 11: Layout II: Three screen display linked to the tablet screen images, with no 3D model available to display. The screen images can be changed to any of the four tablets shown.

In layout III, shown in FIG. 12, the teams were provided with a single interactive whiteboard for the team to use rather than tablet PC's. In addition, the team was again provided with a PC showing the 3D model linked to the leftmost screen, adjacent to the interactive whiteboard. This layout should have provided lower parallelism with the display for the team, with reliance on only the interactive whiteboard. The reprocessability should be high, but slightly lower than the tablets because only one set of sketches is available at a time rather than two or three. The symbol variety should be the same as that of layout I, with the exact same sketching capabilities and the availability of the 3D model.

FIG. 12: Layout III: An interactive whiteboard and an additional large screen are used. The interactive whiteboard is used for sketching, with the added screen run from the PC for navigating the 3D model.

In layout IV, shown in FIG 13, the teams were again provided with a single interactive whiteboard for team use, but no 3D model or additional PC were provided. The team had the ability to sketch on the interactive whiteboard, but no 3D model use or changing to different displayed images. The reprocessability should have been consistent with layout III, and lower than layouts I and II. The symbol variety again was high and flexible with the sketching capabilities, but also lowers than layouts I and III since it was lacking a 3D model.

FIG 13: Layout IV: An interactive whiteboard is available to the teams for sketching their site plan designs.

The four layouts provide fairly consistent symbol variety, the main difference being the availability of the 3D geometry. The major differences were the parallelism of the input potential, and if there is value in the reprocessability or persistence of the content shown on the separate screen displays.

4.3 Observational Study

When considering the four configurations and the coding framework, the use of observational studies was chosen for evaluating and analyzing the value of the interactive workspace and its traits. Observational studies are a commonly employed methodology within the fields of social sciences, though it is hard to say for certain when the practice truly began (Wax 1971; Bauer et al. 2000). The concept behind observational studies, simply put, is that when curious about why a certain phenomenon occurs, people are likely to try to observe it to more fully understand. In utilizing observation as a rigorous method for studying human interactions, new technologies now enable researchers to video and audio capture the activity, and utilize computer software to define frequency and duration of any variety of tasks or activity which takes place to a very precise level. Utilizing a defined coding schema for analyzing the video content allows for the measurement of the reliability and validity of the observation. In this study, inter-rater reliability was used to verify the consistent application of the coding schema to the observed activity (Mathieu et al. 2000). By utilizing observation in conjunction with the detailed content analysis, the study allows for fuller external validity by providing clear context and measurement of the use studied (Cook and Cambell 1979). Following are the details for the coding schema, the analysis, and the results and discussion of the outcomes.

4.3.1 Analysis

For the study undertaken, the observations identified two simple areas to analyze the content of the lab activity, the discussion time contributed by each team member and the time each spends interacting with the interactive workspace. With the use of a 15 minute sample video demonstrating both discussion and interaction, the reliability for coding element was reliable above a 95% level, ensuring a simple and reliable coding schema for use of the content analysis. Table 4 demonstrates the method used for evaluating the level of reliability. A sample of the individual coding durations and reliability levels are demonstrated in Table 4.

Table 4: Example reliability ratings for individual discussion contributions.

Category	**Coder 1**	**Coder 2**	**Reliability Level**
	Total time (min:sec)	Total time (min:sec)	
Person 1	0:47	0:50	99.7 %
Person 2	2:04	1:44	97.8 %
Person 3	2:59	3:15	98.3 %
Person 4	6:05	6:38	96.4 %
Facilitator	0:00	0:00	100.0%

The analysis required the coding of the 24 videos taken during the lab activities. The duration of the time in the lab was 45 minutes but the actual time varied slightly, so to allow for comparison of the data the items are not identified as durations in minutes and seconds but as a percentage of time spent during each video.

4.3.2 Results and Discussion

The first item reviewed after analyzing the video content was average contributions by the team members within each configuration to see if there were obvious differences. In FIG. 14 the average discussion times show that there is little difference amongst the various configurations regarding the average contribution by team members, indicating that the general discussion amongst teams probably followed a typical level of discussion for each team, and that those discussions were relatively comparable given that they are different teams using different lab configurations. So the configuration does not seem to directly relate to different levels of discussion or time spent talking amongst team members.

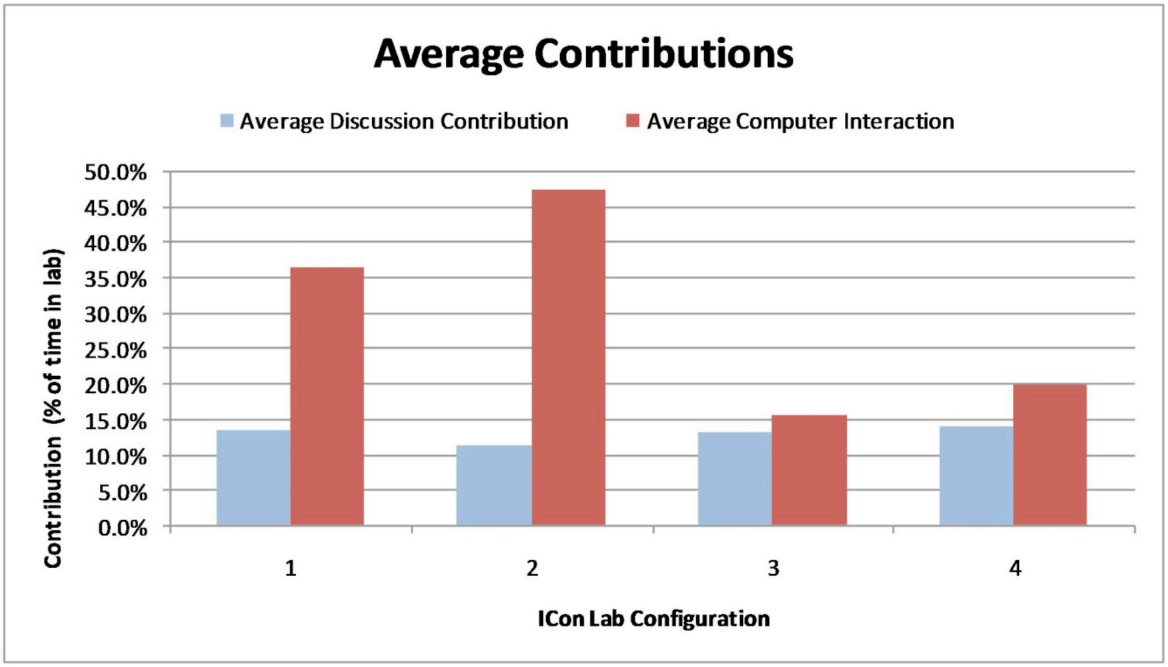

FIG. 14: Chart showing the average contribution by team members through discussion or interaction, broken down by the four ICon Lab Configurations.

When considering the time spent interacting with the interactive workspace from FIG. 14, it is clear that the teams within configurations 1 and 2 spent noticeably more time at an individual level than did the teams in configurations 3 and 4. The main split between the first two configurations and the latter two were that configurations 1 and 2 were using tablet PC's for sketching the site plans and each team member had a tablet PC available to use. In configurations 3 and 4, the teams were sharing a single interactive whiteboard for sketching the site plans and the board did not allow for multiple user interaction, limiting the sketching to one user at a time.

As shown in FIG. 15, the individual levels of contribution to the discussion vary. The discussion levels shown in FIG. 14 indicated the average contribution by team member, but FIG. 15 charts each person's discussion contribution relative to their layout. Again, the range of contributions is consistent within the layouts, showing comparable levels of discussion with no layout showing significant difference in the manner of discussion. Each configuration had some teams which interacted in a balanced manner with relatively equal levels and teams with some high contributors and low contributors.

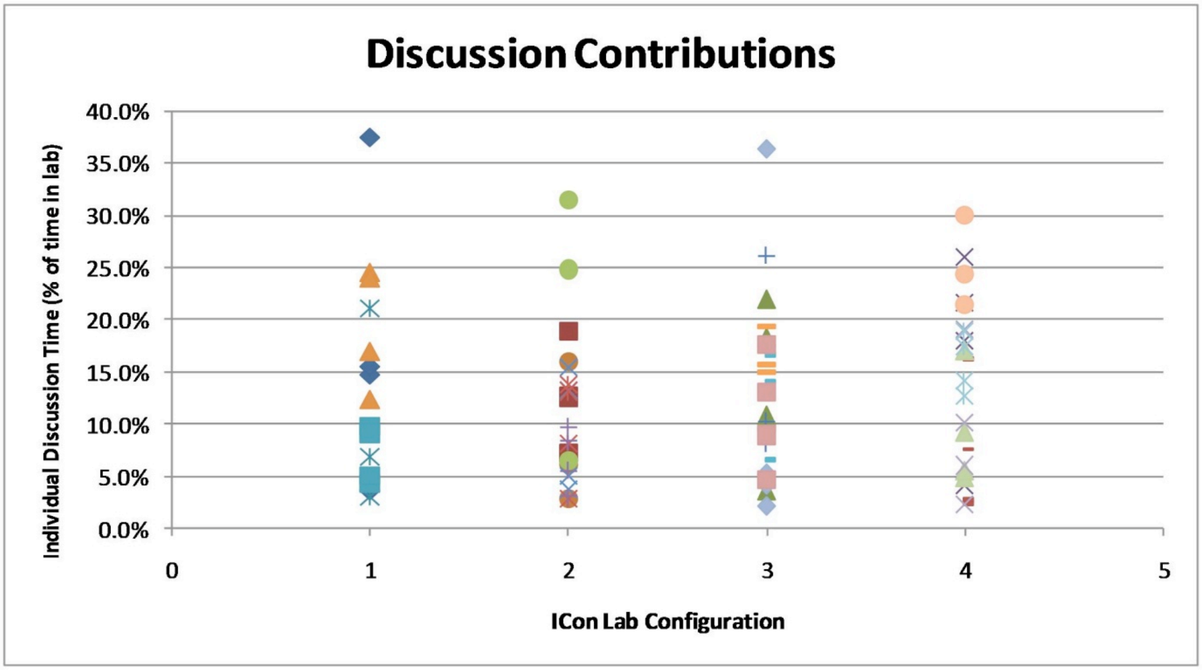

FIG. 15: Chart showing the individual contribution levels for the discussion broken down by lab configurations.

Considering the individual contributions through interaction with the workspace, FIG. 16 shows the individual interactions and clearly indicates that teams in configurations 1 and 2 utilized the tablet PC's more extensively at an individual level than did the teams working with the interactive whiteboard. An interesting note is that the range in levels of contribution when utilizing the tablet PC's is dictated at an individual level and thus there is a greater overall range of use with the tablet PC's. With the interactive whiteboard, the use equates to a zero sum game with use by one person detracting from the available use for another team member.

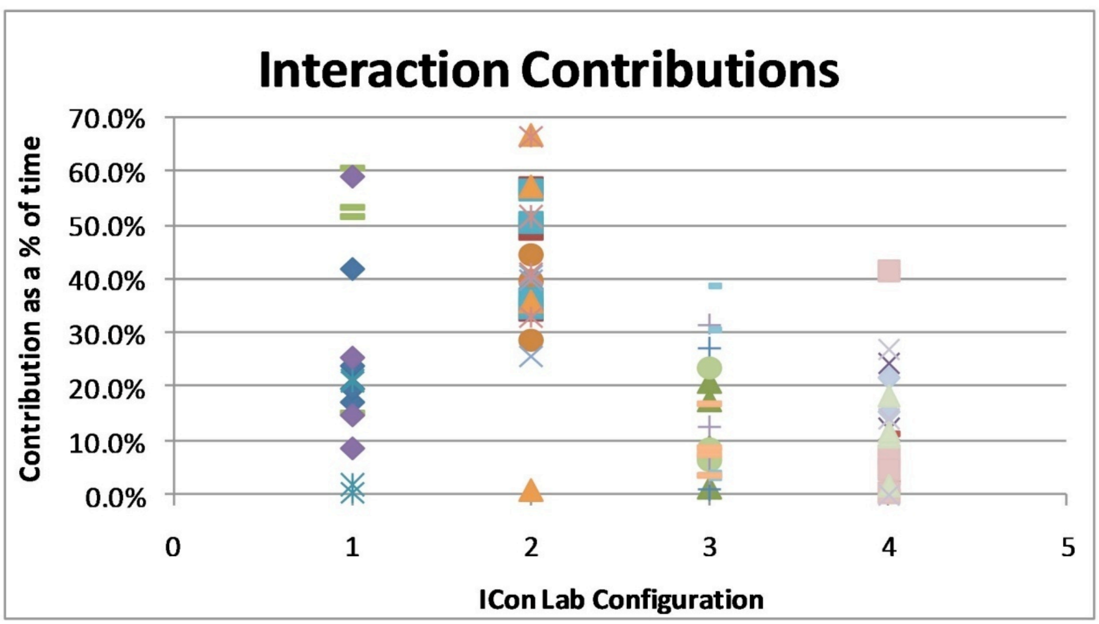

FIG. 16: Chart showing the individual contributions using the interactivity available through the workspace, broken down by lab configurations.

When considering the overall level of contribution, the times spent interacting with the workspace and through discussion were combined by adding the levels of contribution for each item for each individual. The result is the data shown in FIG. 17. The interesting items to note are that the range of contributions are smaller for the teams utilizing the tablet PC's, configurations 1 and 2. While the range for the interactive whiteboard teams, configurations 3 and 4, grew larger. Also, both the lowest and highest contribution levels for tablet PC teams are greater than the corresponding lowest and highest contribution levels for the teams in configurations 3 and 4 utilizing the interactive whiteboard.

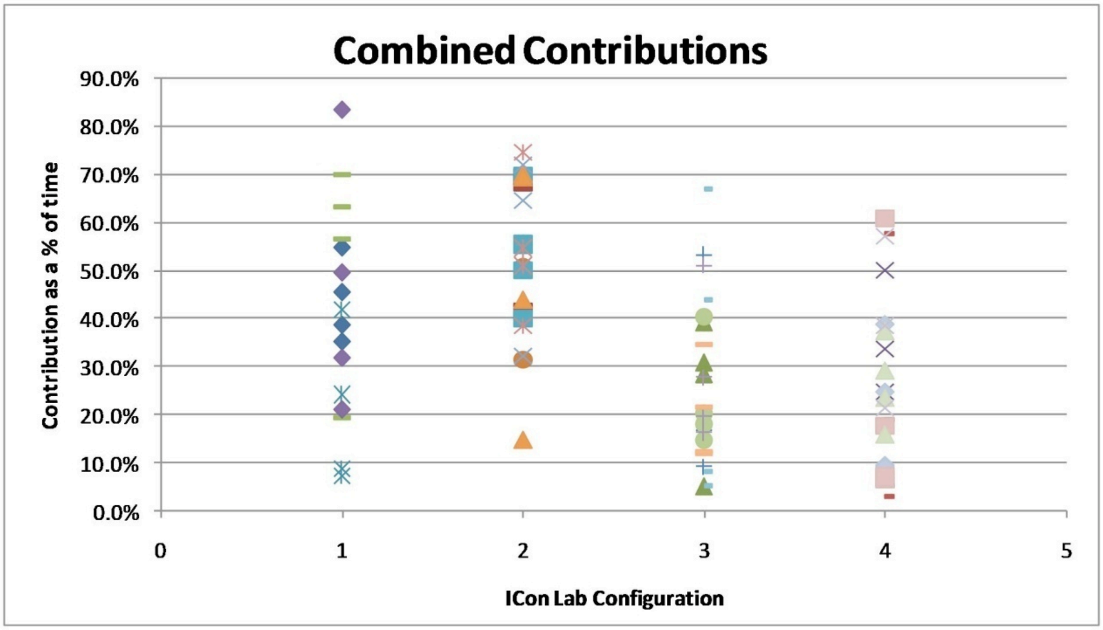

FIG. 17: Chart of combined contributions of workspace interaction and team discussion broken down by configuration.

Along with looking at the overall times interacting with the tools provided in the workspace, the specific uses were tracked to identify the frequency with which teams utilized the 3D model, sketched, or wrote textual notes. Of the 12 groups provided with the 3D model, only one made measurable use, utilizing the model to take dimensions for reference when developing the site layout and two groups spent some time navigating the model while discussing particular items. With regard to sketching compared to writing of notes, more than 95% of the activities taking place where the team members were writing on the displays were for sketching activities for the entire population. There were noted differences in the frequency of writing when comparing teams with the tablets to teams using the interactive whiteboard, with the teams utilizing the tablets more likely to take notes on the shared display, though almost every team took some notes.

The evaluations from the site plans were compared by layout to identify if the use of one particular lab configuration impacted the quality of the design. The scores from each of the four layouts were averaged. The average scores for the two layouts utilizing the tablet PC's was slightly higher, but when evaluated the statistical difference was not found to be significant. The significance is quite possibly an issue of the small sample size utilized in the study, and larger samples may demonstrate more accurately whether one configuration correlates to a higher quality solution.

5. CONCLUSIONS & FUTURE WORK

The framework presented demonstrates a means of planning the characteristics of an interactive workspace to match the interaction of the team and workspace with the objective of the task. The effectiveness of the collaboration is not defined in terms of the subjective quality of the outcomes, but as improving the ability of the team to participate and communicate in the tasks undertaken. In the study demonstrated, the concepts of slower feedback, higher parallelism, and higher reprocessability were found to be better embodied in the use of multiple tablet PC's shared on several displays than the use of a single interactive whiteboard. The persistence of each individual's sketches allowed for more deliberation and higher reprocessability before providing feedback. The multiple screens and interactions points provided high parallelism, with sufficient symbol variety in the form of sketching capabilities, with written text and 3D geometry having some value.

The framework demonstrates a process for comprehensively planning the traits of an interactive workspace within the context of facility design and construction tasks. It demonstrates the value in planning the modal interactions with shared information during collaborative tasks, and the impact it has on team communication. Companies could take the framework, identify the common set of tasks they perform collaboratively, and develop a set of traits to explore a flexible interactive workspace to meet all of those needs, or a focused application for one or two high value collaborative tasks.

As newer media tools and concepts for ubiquitous and pervasive computing change the time, location, and manner of information sharing processes, frameworks such as the one presented will become increasingly important for firms to identify the capabilities and processes they are pursuing, and to then objectively select the tools and technology that best fulfils those needs. The framework presented will continue to be used to develop a comprehensive system for planning a company's implementation and metrics to evaluate that implementation and refine it. To balance that work, continued validation of the framework for other tasks will continue to more fully define the relationships between the communication factors and the characteristics of an interactive workspace. Those relationships will also continue to be validated to ensure that use of the framework will lead to the most effective characteristics and implementations for given tasks.

With the value of such spaces for improving communication, both face-to-face and computer-mediated, the implementation of such ICT tools is already occurring, and is only expected to increase as the demand for more sustainable and high performance facilities drives the need for tighter integration and greater use of computing tools for analysis and simulation of building and infrastructure projects. This framework simply provides a thorough process for defining the needs and determining the most valuable aspects for effective use of these tools for collaboration.

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