Development of Indices for User Perceptions of Interactive Technologies in Construction Engineering

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Abstract

This paper presents the development of indices for assessing user perception of interactive technology elements. An exploratory factor analysis (EFA) was performed using data from Leicht (2009), where teams of engineering students (n=82) were asked to perform a collaborative site planning activity in interactive environments and assessed through a post-activity questionnaire. Two factors, media interaction and team interaction, were identified in the analysis. The two indices for user perception are a 4-item Interactive Media Index (IMI) and 4-item Interactive Team Index (ITI), with Cronbach alphas of 0.80 (IMI) and 0.82 (ITI). The indices provide new assessment metrics to aid researchers in evaluating and researching interactive workspaces. Where previous user perception assessment focused on the usability of a system, these indices provide additional metrics for assessment of technology usage and collaborative usage in tandem. The IMI and ITI are presented and implications are discussed.

Keywords: interactive workspaces, collaborative engineering tasks, factor analysis

1 Introduction

The use of interactive technology (e.g., multi-modal, multi-input and output systems) by Architectural, Engineering, and Construction (AEC) Industry project teams has increased in recent years. The 2014 SmartMarket Report reported one of the emerging uses of Building Information Models was immersive visualization for communicating complex project information with multi-disciplinary teams (Jones and Bernstein 2014). The growing interest in visualization indicates an industry need for advanced techniques to support immersive tools and interactive media. The dynamic of interaction between the user and these systems, as well as among the individuals using these systems, is an important topic for understanding the development of new tools and how they can best be used. However, there is a lack of research on how multi-modal systems influence collaborative co-located teams. Development of interaction indices will aid researchers by providing a tool for evaluation of user perceptions' of these systems.

1.1 Theoretical Background

In communication and media research, the computer mediated communication (CMC) domain often investigates how people communicate with and through devices. The interaction focus in this domain is on the role of the computer as a mediator and on the person-to-computer communications. In various debates on the definition of interactivity in the context of new technology, the communication between individuals is often ignored in order to focus on the person-to-computer and the person-to-person mediated through computer context of communication (Bucy 2004). This approach diverges from the traditional definition of interactivity by Rafaeli (1988), which constrains interactivity in the context of inter-personal communication. With technology developments often targeted to aid teams to communicate synchronistically in physically co-located spaces, more work is needed in order to investigate interactivity among media and team members' communication.

In the information sciences fields, human computer interaction (HCI) research focuses on how a person interacts with the computer directly, usually without much emphasis on the content of communications. HCI research is currently evolving to encompass more human-to-human communication aspects. Still, research is primarily focused on communicating through and with devices, and not with both people and devices concurrently. The typical methods of evaluation of information visualization are controlled experiment of design elements, usability evaluation of a tool, controlled experiment comparing two or more tools, and case study of a tool or set of tools (Plaisant 2004). Current evaluation practices either focus on the medium/modality of the information (HCI focus), or the communication with individuals mediated through the medium/modality (CMC focus). Tuch et al. (2012) used four different usability perception indices to evaluate interaction elements of an online clothing store. They found peoples' perceptions of usability to be directly linked to usability manipulation, which mediated their evaluation of the aesthetics of the interface architecture. Use cases which incorporate both human-to-human and human-to-computer interactions are not typically evaluated within the domains of CMC nor HCI.

The computer, or the application/tool, can be seen as the source instead of solely as a medium (Sundar and Nass 2000). This suggests people interact with computers in similar ways that they would interact with other humans. Computers are not only tools, like traditional media of newspapers, text, and television; they elicit more complex interactions and reactions from individuals. When a group of people are placed together with interactive digital content to work on a complex problem, such as a construction site planning, they interact both with each other in a collaborative way and with a computer. Both the team dynamics and the media dynamics play potentially important roles in how teams collaborate effectively to achieve solutions. In this paper, the researchers investigate the factors involved in a post-activity questionnaire evaluating elements of interactions in a complex interactive team and media environment. The purpose of the study is to aid future analysis and research into peoples' perceptions of their interactions with these complex and novel systems.

1.2 Interactive Workspaces

Interactive Workspaces (IWs) are collaborative spaces developed for groups of people to collaborate with digital content. There are several definitions of interactive workspaces. Johanson and Fox (2004) defined interactive workspaces as "technology-augmented team-project rooms that are used by groups to do collaborative problem solving." These workspaces are described as as a sub-class of ubiquitous computing environments within ambient spaces. Lather (2016) defined interactive workspaces as "physically located technology- and media-enabled project spaces facilitating human centered interaction and meaningful collaboration of project team members." These spaces utilize heterogeneous devices and software, often feature large format displays, enable content sharing and media viewing, and incorporate multi-modal interaction. Both definitions focus on the spaces leveraging heterogeneous devices for project teams.

Interactive and collaborative technologies, such as those engineering project teams use, have a specific emphasis on communication and visualization. Russell et al. (2005) explored three different interactive workspaces and described four areas of design requirements for these specific types of spaces: heterogeneity, dynamism, robustness, and interaction techniques. Lather (2016) documented interactive workspaces in the building engineering fields and found these facilities are used primarily for visualization and analysis tasks, and secondarily for generating information. Generating is one of the five main categories of building information modeling uses (Kreider and Messner 2013) and the use most closely aligned with a site planning activity. In such a use, the interactive technology can potentially aid the collaborative problem solving and idea generation process for various tasks within a project.

One of the key technological affordances offered by interactive workspaces is the multi-modal human computer interaction (MMHCI). In a survey of MMHCI, Jaimes and Sebe (2007) discuss ambient spaces, such as "smart meeting rooms," as one of the six major application areas for

MMHCI. Although interactive workspaces are a specialized version of ambient spaces, they present a complex interaction use case. As people increasingly expect access to and flexibility with manipulating digital information, the need for interacting with that information beyond the desktop environment will increase (Jaimes et al. 2006). For engineers and building scientists, this means developing novel interactive environments that aid new forms of interaction for both individuals and teams.

2 Methodology

The methodology utilizes an exploratory factor analysis to investigate user perception of touch-enabled technology and team dynamics from a post-activity questionnaire. The development presented is the initial effort of a larger study investigating cognitive style impact on technology usage and performance for interactive technology, thus data from a 2008 study with a touch-enabled technology is used for an exploratory factory analysis.

2.1 Design

The original design of the experiment for this research stems from research completed in 2008 (Leicht 2009). In the quasi-experiment the media technology (tablets vs. touch-enabled whiteboard) was not statistically different in terms of team use (i.e., utterances and durations) (Macht et al. 2013), therefore, the media technologies are treated as comparable for the purposes of user perceptions. The approach uses an exploratory factor analysis (EFA) with the 2008 data to identify how the questions align with aspects of user perception to be used later with an additional sample in a confirmatory factor analysis and structural equation model.

2.2 Sample

The sample data was collected from 82 students in a third year introductory construction engineering course over a single year time period (2008). All students were in their third year of architectural engineering education at The Pennsylvania State University in a required course on construction engineering. All students were involved in the activity as part of course requirements. Sample data came from those who consented to the use of their data from both the site planning activity and other relevant performance metrics as part of this study. Although the exercise was completed by teams, all respondents completed individual assessment of the technology, thus all analysis was performed on the individual level.

2.3 Procedure and User Task

The procedure included two types of technologies: touch-enabled interactive whiteboard and multiple tablets. Each group was randomly assigned which technology setup for their group and they were asked to perform a site planning task. The site planning task was completed within an allotted time, no greater than 60 minutes. Students were assigned to teams of 3-4 for a series of projects using the same case study building throughout the semester. The targeted project assignment required the students to conduct construction site planning. Each team was provided either a touch-enabled screen or a set of tablet computers for conducting an initial planning activity for two to three construction phases, for no longer than 60 minutes including both the activity and survey. After the activity, each participant was given the 16-item questionnaire with questions targeting how the students felt about the technology in general and its role in assisting team dynamics or collaboration (Leicht 2009; Leicht and Messner 2009).

2.4 Immersive Construction Lab Environment and Stimulus

All participants used the Immersive Construction Laboratory (ICon Lab), an interactive workspace at The Pennsylvania State University, to conduct their site planning activity. The workspace is equipped with a large three-screen display, LCD side display, and a main controller allowing video switching among screens. Additional features of the space exist for video-conferencing, immersive visualization, and content switching, which are presented in other work (see Leicht et al. 2012; Liu et al. 2014). Tables and chairs are available in front of all displays, which are available for tablets and personal use. To the left of the main display, a single touch-enabled interactive whiteboard, approximately 0.9m (3ft.) tall and 1.2m (4ft.) wide, is available for use with a console located directly behind it (see Figure 1).

During the site planning task, researchers were present observing the activity without aiding participants. Teams were tasked to use an interactive whiteboard (SMART Technologies' SMART Board®). On the screen, a site plan was made available as a PDF in a slideshow format (Microsoft's PowerPoint) with the tracing attribute enabled on the interactive whiteboard. Multiple digital pens and a digital eraser were made available to the teams throughout their site planning activity. Before beginning, teams were briefed by a research assistant on how to use the interactive whiteboard and on the site planning task. They were tasked with initial brainstorming several construction phases of a building project they had become familiar with for at least 6 weeks prior, through other coursework and projects. Although they were familiar with the building and its systems, most students had never previously performed a site planning activity. In addition to the task instructions, a list of common items on a site plan were provided. Teams were given 60 minutes to complete their initial plans. Their usage of the time and space were wholly up to the teams.

Figure 1: Interactive Workspace Layout: Touch Enabled Interactive Whiteboard (left), Tablet Layout (right)

2.5 User Perception Questionnaire

The survey was a 16-item questionnaire developed to understand how individuals felt about a group activity when using different interactive technologies. Each question was set to a 5 point Likert scale (i.e., strongly disagree [1] to strongly agree [5]) (Leicht 2009). The questions ranged from: an individuals' perception of how the technology functioned in assisting the task overall: "The interface for drawing was intuitive and easy to use." to an individuals' perception of how the technology facilitated collaboration: "Everyone in the group contributed ideas and suggestions during the task." The initial design of the questionnaire was arbitrarily ordered and designed to capture a simple understanding regarding user perceptions of the touch-enabled technology for a team task (Leicht 2009).

Based on the relatively arbitrary nature of the questionnaire's construction, how the various user perceptions related to each question within the survey needed to be determined. Since the purpose of the factor analysis is to identify factors for analysis in future studies, some questions were no longer relevant to the original questionnaire. The first two questions that were eliminated from analysis due to emphasis on a workspace environment that is unlikely to be replicated in other interactive workspace environments. Additionally, the focus of the research is on developing factors for interaction with touch-enabled technology. These questions were: "A 3D representation of the building is needed for the site planning task" and "Having multiple screens allowed us to better visualize the information". After further evaluation, only one more question was eliminated from analysis based on the premise that it was only applicable to an individuals' general perception on new technology, not the collaborative environment or the team dynamics; thus "I usually embrace and I am comfortable using new technology" was removed from the questionnaire analysis. The original 16-item site planning questionnaire was therefore reduced to 13-items (see Table 1).

2.6 Exploratory Factor Analysis

An exploratory factor analysis (EFA) was performed on the data with the reduced 13-item questionnaire using the *psych* package in R (Beaujean 2013; Revelle 2012). A Scree plot to determine the optimal number of factors using various algorithms was constructed. Based on the recommendations of the literature, the oblique rotation results were selected to create factors that were less correlated between each other (Beaujean 2013; Osborne 2015; Yong and Pearce 2013). Since the EFA was only run on a data set of 82 individuals the threshold for accepting factor loadings was raised from the traditional 0.3 cutoff to any loadings less than 0.4 (Osborne 2015; Yong and Pearce 2013).

Table 1 Original Questionnaire and Final Factor Model

Item Code	Item	Factor IMI	Factor ITI
Item - 1	I usually embrace and I am comfortable using new technology.*	-	-
Item - 2	I enjoyed performing the Site Planning task in the ICon Lab.	-	-
Item - 3	The large display was helpful for completing the site planning task.	-	-
Item - 4	Our team collaborated better than we normally do when working together.		x
Item - 5	Everyone in the group contributed ideas and suggestions during the task.	-	-
Item - 6	The ability to write and sketch on the screen was helpful.	x	
Item - 7	A 3D representation of the building is needed for the site planning task.*	-	-
Item - 8	Team members contributed more than usual.		x
Item - 9	The ability to meet in a separate space made us more productive.		x
Item - 10	The ability for all members to contribute using the display was valuable.	x	
Item - 11	The interface for drawing was intuitive and easy to use.	-	-
Item - 12	Some team members were not involved in the site planning process.	-	-
Item - 13	This environment allowed us to communicate more effectively than usual.		x
Item - 14	I enjoyed using the sketching capabilities.	x	
Item - 15	We would use a space like this in the future if it is available for similar tasks.	x	
Item - 16	Having multiple screens allowed us to better visualize the information.*	-	-

Note: Gray text depicts item is not present in final model
* depicts removal from factor analysis

3 Results

3.1 Descriptive Statistics

The demographics was comprised of 78% male undergraduate students and 22% female undergraduates. Participants have a majority (95%) age range of 20-22. Typical task and survey completion time ranged from 45 to 60 minutes.

3.2 Exploratory Factor Analysis (EFA)

The 13-item questionnaire was found to be highly inter-correlated and statistically sound with low skewness and kurtosis (see Table 2). The EFA displayed two factors with an eigenvalue greater than one implying two factors, which was confirmed via the Scree plot, with a root mean square of the residuals (RMSR) being equal to 0.07. Factor 1 had an eigenvalue of 3.09 accounting for approximately 49% of the variance, whereas Factor 2 had an eigenvalue of 2.86 accounting for approximately 45% of the variance (see Table 3). The results show alignment of six items into Factor 1, five items into Factor 2, and two items that did not fit into either factor and had high uniqueness scores, greater than 0.70. The two items which did not fit into either factor were Item-5, “everyone in the group contributed ideas and suggestions during the task” and Item-12, “Some team members were not involved in the site planning process.” Factors 1 and 2 have acceptable Cronbach Alpha’s for relatively high reliability, 0.80 and 0.82 respectively, and were correlated between themselves at 0.55. The proportion explained by Factor 1 was 52% and the proportion explained by Factor 2 was

48%. The Hofmann's Index of Complexity had a mean of 1.33 for all factors and relatively simple for most individual items, (i.e., close to one), demonstrating that these items belonged in only one factor (Pettersson and Turkheimer 2010). Table 3 illustrates the factor loadings, communalities, uniqueness, and complexity for the site planning questionnaire.

Item-2, Item-3, and Item-11 all had low factors loadings (less than 0.5), high uniqueness factors (greater than 0.6), and high complexity factor (greater than but not equal to 1.5). Therefore Item-2, "I enjoyed performing the Site Planning task in the ICon Lab.", Item-3, "The large display was helpful for completing the site planning task.", and Item-11, "The interface for drawing was intuitive and easy to use." were eliminated. All the items in Factor 1 correspond to sketching, display and interacting with the workspace, thus this factor has been labeled as "Interactive Media Index". All the items in Factor 2 correspond to the teams' collaborating, contributing and communicating, thus this factor can be labeled as "Interactive Team Index" (see Table 1).

4 Discussion

The exploratory factor analysis provides an initial two factor structure for Interactive Media Index (IMI; Factor 1) and for Interactive Team Index (ITI; Factor 2). IMI includes 6 items and ITI includes 5 items on a 5 point Likert scale. These indices were developed with groups of 3-4 individuals working on a common task of a site planning activity. Although the use of the facility for the activity was required, no direct output of the activity was graded, nor was their usage of the technology or space graded. The participants were relatively free in how to use the space during their appointed time. Upon evaluation of participants' responses, two factors were determined to be the appropriate model for the EFA.

The IMI is constructed of four elements. The highest loading were the items "the ability to write and sketch on the screen was helpful" and "I enjoyed using the sketching capabilities" which relate to the individual using the media. The other two items were "The ability for all members to contribute using the display was valuable" and "We would use a space like this in the future if it is available for a similar task" and relate to the team using the devices and space. These four combine to create the Interactive Media Index. The ITI is made up of the following items from highest loading to least: "team members contributed more than usual," "our team collaborated better than we normally do when working together," "this environment allowed us to communicate more effectively than usual," and "the ability to meet in a separate space made us more productive." These items emphasize the activity or the space and imply improved team dynamics such as collaboration, communication, and contribution. These four items combine to focus on the interaction of the team during the task.

Additional affordances of the technology should be considered in future implementations. The questionnaire was developed specifically for use in sketching on large formatted displays for use in site planning tasks. However, other applications can test the questionnaire by replacing the task type, interactive workspace named, as well as the representational ability used (e.g., "write" or "sketch"), if those vary in the research. The researchers foresee new developments in interfaces and tools may require the questionnaire to be adjusted to affordances offered by different media, input, or haptic feedback systems (e.g., joystick, stereoscopic display, head mounted display) in order to expand the applicability of these indices.

Other related elements to interaction, which were not explored in this development, were navigability, transversability, and wayfinding. These elements can have an impact on user perception of technology as shown in Balakrishnan and Sundar (2011) with both transversibility and navigability found to impact spatial presence. Spatial presence, or feeling present within a space, is an important psychological construct of spatialized interactive media, such as new immersive media used for design and construction. The context of usage of technology and not just the interactions with its interface can provide interesting insights into spatial reasoning, knowledge retention, and potentially other communication and collaboration relationships that warrant further exploration.

Future research will investigate the IMI and ITI for team collaboration and interaction within interactive workspaces. Future analysis on a larger dataset of a similar experiment can be used to confirm the factor analysis developed and presented in this paper. Of special interest is how user perceptions of both the technology and collaboration coupled with measured communications of team members relate to behavior and performance. Future work will need to develop methods for evaluating team performance measures and document individual technology preferences to aid hardware, software, and tool development.

The technology being deployed in a commercial setting for the AEC industry is varied much like the media richness of modern society. For the technology which is specifically focused on aiding teamwork, synchronous tasks, and decision making, evaluation of the technology and research into its impacts (such as on the design and construction process) are only starting to emerge as topics in visual analytics (Andrienko et al. 2010; Laha and Bowman 2012; Tory 2014). Research in these advanced visualization facilities has, to date, focused on development of taxonomies and ontologies of the technology to aid research (Laha et al. 2015; Lather 2016; Rentzos et al. 2012), experiments of specific tools within the facilities (Balakrishnan and Sundar 2011), or on case studies within these facilities (Liu et al. 2014). This work complements those efforts by developing a two factor questionnaire to understand user perceptions of interactive technology on both a collaboration and technology focus. Since most technologies deployed are tools to aid some type of communication or collaboration with other individuals, this work is valuable to aid researchers to investigate not only individual assessment of technology usage but collaborative usage as well.

5 Conclusions

This paper presents the development of two indices for assessing user perception of various components of a complex interaction system where teams are interacting with multi-modal content. The two factors roughly follow the theoretical background in describing interaction with systems as separate from team or group interactions. The indices will be useful for aiding assessment of teams working with complex interactive workspaces, and can be used in conjunction with other assessment measures such as performance metrics, time studies, and content analysis. Future work will explore how perceptions may align with performance as well as how personal perceptions or preferences may influence the group dynamics when using interactive digital content.

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Table 2 Descriptive Statistics for Site Utilization Survey

Item Code	M	SD	Skew	Kurtosis	Q2	Q3	Q4	Q5	Q6	Q8	Q9	Q10	Q11	Q12	Q13	Q14
1. Item - 2	3.90	0.95	-1.00	1.21												
2. Item - 3	4.02	0.85	-0.53	-0.42	0.52 ***											
3. Item - 4	3.37	0.99	-0.09	-0.25	0.45 ***	0.36 ***										
4. Item - 5	4.02	0.96	-0.80	0.09	0.46 ***	0.23 *	0.38 ***									
5. Item - 6	4.10	0.90	-1.00	0.86	0.37 ***	0.57 ***	0.27 *	0.44 ***								
6. Item - 8	3.09	0.96	0.00	0.12	0.25 *	0.32 **	0.66 ***	0.19	0.13							
7. Item - 9	3.30	0.99	-0.40	0.01	0.24 *	0.23 *	0.45 ***	0.38 ***	0.45 ***	0.45 ***						
8. Item - 10	3.79	0.83	-0.38	-0.35	0.27 *	0.43 ***	0.40 ***	0.37 ***	0.61 ***	0.21	0.42 ***					
9. Item - 11	3.96	0.92	-0.58	-0.52	0.08	0.11	-0.08	0.30 **	0.26 *	-0.04	0.09	0.12				
10. Item - 12	2.29	1.00	0.35	-0.66	-0.09	-0.08	-0.07	-0.33 **	-0.20	0.13	-0.09	-0.22 *	-0.14			
11. Item - 13	3.29	0.88	-0.49	-0.40	0.45 ***	0.42 ***	0.60 ***	0.37 ***	0.35 **	0.60 ***	0.55 ***	0.34 **	-0.02	-0.03		
12. Item - 14	4.07	0.93	-0.97	0.61	0.27 *	0.30 **	0.19	0.30 **	0.73 ***	0.05	0.39 ***	0.52 ***	0.45 ***	-0.17	0.26 *	
13. Item - 15	4.06	0.82	-0.51	-0.45	0.42 ***	0.44 ***	0.32 **	0.27 *	0.56 ***	0.17	0.27 *	0.29 **	0.05	-0.19	0.44 ***	0.59 ***

Note: Data from Sample 1 ($n = 82$). Response scale ranged from 1 (strongly disagree) to 5 (strongly agree).
Correlations: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3 Final Factor Loadings, Communalities, Uniqueness, and Complexity for Site Utilization Survey

Item Code	Item	EFA Factor Loading IMI	EFA Factor Loading ITI	Communality h^2	Uniqueness u^2	Complexity com
1. Item - 2	I enjoyed performing the Site Planning task in the ICon Lab.	0.24	0.40	0.319	0.68	1.6
2. Item - 3	The large display was helpful for completing the site planning task.	0.40	0.30	0.382	0.62	1.9
3. Item - 4	**Our team collaborated better than we normally do when working together.**	-0.13	**0.88**	**0.667**	**0.33**	**1.0**
4. Item - 5	Everyone in the group contributed ideas and suggestions during the task.	0.36	0.25	0.293	0.71	1.8
5. Item - 6	**The ability to write and sketch on the screen was helpful.**	**0.94**	-0.06	**0.818**	**0.18**	**1.0**
6. Item - 8	**Team members contributed more than usual.**	-0.33	**0.93**	**0.640**	**0.36**	**1.2**
7. Item - 9	**The ability to meet in a separate space made us more productive.**	0.24	**0.48**	**0.418**	**0.58**	**1.5**
8. Item - 10	**The ability for all members to contribute using the display was valuable.**	**0.57**	0.16	**0.448**	**0.55**	**1.2**
9. Item - 11	The interface for drawing was intuitive and easy to use.	0.48	-0.27	0.159	0.84	1.6
10. Item - 12	Some team members were not involved in the site planning process.	-0.31	0.12	0.072	0.93	1.3
11. Item - 13	**This environment allowed us to communicate more effectively than usual.**	0.01	**0.79**	**0.625**	**0.37**	**1.0**
12. Item - 14	**I enjoyed using the sketching capabilities.**	**0.92**	-0.19	**0.683**	**0.32**	**1.1**
13. Item - 15	**We would use a space like this in the future if it is available for similar tasks.**	**0.57**	0.13	**0.424**	**0.58**	**1.1**
		Eigenvalue % of Variance		**Total Communality**		**Mean Item Complexity**
		48.99%	44.87%	5.948		1.33

Note: Data (n = 82), bold indicates presence in final factor model.