Exploring the feasibility of using tabletop displays for Construction Design Meetings

by

Subhanil Chakrabarty
B.E, University of Burdwan, 2006

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Supervisory Committee

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Abstract

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We have investigated the feasibility of using digital tabletop displays during design team meetings to improve access to design information. To achieve this goal, we have applied various design guidelines for tabletop interface design and requirements for digital meeting scenarios in order to implement design ideas (in a prototype named Mozaic) that specifically cater to design team meetings. Mozaic intends to improve information retrieval and browsing activities during meetings thereby improving information access through a tile based layout, pop-up menu control and filtered list. We have evaluated the features of Mozaic through an exploratory study on a tabletop display (in comparison to a commonly used desktop software tool, which was also used on the tabletop) to evaluate various design ideas and ferret out design ideas for future iterations of Mozaic. We present the result of this study as observations and user feedback and discuss them in the light of interface development for design meeting situations.

Table of Contents

List of Tables

List of Figures

Acknowledgments

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Dedication

For my parents –
for their undying and unconditional support.

Chapter 1: Introduction

The construction industry has a well established set of work practices. These work practices primarily involve extensive and methodical project planning, design and execution of the plan. It has been demonstrated that the planning and design phase of a construction project is crucial to a project's success. It is a well established fact that faulty design at the initial phase of a construction project is attributed to 78% of problems in quality [25] and around 25 % of time is lost during construction due to design deficiencies [54]. Therefore, the design phase of a construction project is crucial for a project's success in terms of project quality, time management and cost effectiveness [9].

We present Mozaic, a collaborative interface for table top displays that is designed to aid the processes of *design development* and *design coordination* (discussed later). Mozaic is designed to improve access to digital documents that are used by design teams during meetings. Mozaic incorporates three main modules - a tile based display, pop-up menu based tool collection and a filtered list. The objective of this interface is to understand the effectiveness of these design elements and explore further design considerations in this area. The interface incorporates simple interaction techniques that require minimal effort to learn. The interface is designed to cater to design team meetings where design team members work collaboratively.

Following up several ethnographic studies conducted by other researchers [8, 12, 52], we realised that there are information access bottlenecks during construction design meetings that might be resolved by tools specifically catered to construction design meetings. Design meetings traditionally use paper based artifacts (described later) which often hinders subgroup collaboration and obstructs physical access to shared information. Some meetings however use digital technology in the form of wall displays which does not cater to the needs of such meetings, rather it often becomes a disadvantage to these meetings. This led us to ask about the feasibility of using digital tabletop displays for using and navigating the design documents during design team meeting scenarios. Our approach was to apply existing guidelines for designing a tabletop interface to develop specific design ideas for improving information access during design team meeting scenarios; these ideas were then implemented in a prototype system for tabletop displays. We evaluated our preliminary design by running an exploratory study to find out how the users make use of the proposed design features.

Figure1. Paper based workspace (Photo Courtesy: Mani Golparvar Fard)

1.1 Current Practices in Design Meetings

Design meetings involve "intense collaboration" [41] between design team members and stakeholders who collaboratively discuss the various design and contractual decisions involved in the design of a building. This design process is part of the *design development* [34] phase of construction projects. This phase comes right after the initial project design phase which primarily consists of designing the basic appearance, the building elevations, room configurations and the overall project design. *Design development* involves refinement of the designs in order to comply with the safety and performance standards established by the government, and results in the production of contract documents. The end result of the design development phase involves generating plans and models by several disciplines, namely, mechanical, landscaping, electrical, structural, plumbing, controls, envelope and fire protection. This design development phase involves rigorous team meetings where the team members decide on various aspects of the project ranging from broad design aspects to intricate details [31]. Design development is followed by a *design coordination* phase, in which the design team identifies and resolves conflicts and potential issues between different elements of a building design to ensure that different systems work together to meet the requirements set by a client [52]. However it should be noted here that the term ‘coordination’ has many different meanings in the context of Computer-Supported Co-operative Work (CSCW) but we use it specifically to mean coordination of the design elements. Throughout both design phases the design team regularly meets to review and coordinate their designs to meet the standards and the guidelines of the project. A design team primarily consist of architects, surveyors, draftsmen, civil, mechanical, electrical, structural and fire-protection engineers. The goal of these multi-disciplinary and multi-organizational teams is to work with each other collaboratively within limited time and come to a conflict-free project completion.

The construction meetings can involve both physical and digital *artifacts*. The term *artifacts* or *representational artifacts* (in the context of architectural domain) can be defined as the objects and elements that design team members use to portray their ideas and communicate with other team members. Artifacts can be seen as a “hub of information” that design team members use during the construction project meetings to communicate with other team members. In other words, an artifiact is a formal representation of design ideas, budgetary goals and other relevant construction documents that design teams use to communicate amongst themselves. In this literature we are concerned about the documents that describe design ideas and goals. These include detailed drawings of construction, 2D plans and 3D views and specifications of a construction project. These documents can be digital and / or physical (paper-based) in nature depending on the type of team meeting.

The schematic diagrams consist of floor plans, elevations, sections and details which are collectively referred as a *stick set*. A *stick set* in more general terms is a collection of all these schematic drawings attached together with a yard stick like clamp. It typically includes all designs and drawings related to the multiple disciplines of work involved in the project namely architectural, civil, mechanical, electrical, structural, landscaping and fire protection. This *stick set* plays an important role during a *design development and coordination* meeting where design content of the stick set helps to support various discussions during the meetings.

2D plans and 3D views are often used during these design meetings. Both have their distinct advantages and therefore the team members need to use both types of representations. 2D drawings display intricate information on a sheet, whereas 3D diagrams provide an overall perspective that helps with conflict resolution.

Traditionally the design team meetings were conducted entirely on paper-based static representations of construction projects. Paper-based 2D drawings are widely used to communicate with peers during a meeting even though most of the information is generated electronically.

Now, digital technologies are beginning to be used but evidence from the ethnographic studies [8, 12, 52] indicate that existing technology is insufficient to replace advantages (like navigation) provided by paper. It has been observed that such digital meetings incorporate some use of paper. The concept of the use of digital technologies in meetings is fairly new and therefore there are some challenges [8, 52]. These challenges have often been offered by the design and the complexity of the technology itself [8]. We believe that these challenges can be minimised with simple but effective design considerations.

Construction projects involve translation of paper or computer based design into reality. With the advent of modern digital technology, computer aided drafting (CAD) and manufacturing (CAM) has become an integral part of the design process. The digital media is used to make the drafting process of designs faster and easier. In recent years there is a growing interest in the use of 3D CAD during meetings. 3D CAD information cannot be presented dynamically on paper; and this is one of the reasons why design teams are pushing the use of digital technologies in meetings.

This trend towards the use of digital technology should ensure that access to static 3D and 2D information is smooth. In this thesis, we only focus on ways to smoothly access and display static 3D and 2D information on tabletop displays.

1.2 Bottlenecks in Meetings

The design team meetings play a vital role during the design phase and therefore they have been studied extensively. Tory *et al.* [52] studied the role of the design documents that are central to the meetings and how the team members interact with them to communicate effectively. Cavka *et al.* [8] specifically studied various bottlenecks that arise during the digital meetings and categorised them into context-based bottlenecks and content-based bottlenecks.

It has been observed that bottlenecks may arise due to lack of relevant digital technology at meetings. Deficiencies in current digital technologies include lack of interactivity and inability to reach displayed information. Such inefficient strategies hinder access to information during meetings, particularly when using digital technology. Users in these meetings are often not familiar with the current digital technologies and therefore they prefer not to interact with digital information laid out on a digital display.

Various scenarios cited by Tory *et al.* [52] and Cavka *et al.*[8] highlight the need for shared information that is quickly accessible by the design team members during meetings. Lack of collaborative tools brings different kinds of bottlenecks that add to the time delay. Meetings often take place in conference rooms equipped with digital displays [12, 52] and can be (1) Same place and same time 2) Different place same time, in terms of CSCW space–time matrix [3].

Scenarios depicting bottlenecks in both kinds of collaboration have been noticed. This essentially reflects on the computer and digital display board technologies that are widely used these days.

These ethnographic studies also point out that proper tools designed for design meetings might address the bottlenecks related to information access. Inaccessibility of information may be caused by an inability to find the right information at the right moment or merely by a team member's inability to access the physical location where the information is stored. To elaborate on this, let's have a look at two examples that highlight such issues in meetings. These examples were observed in earlier observational studies of meetings in the architectural domain [12, 52]:

Example 1

At a meeting table an architect needed to open up an architectural drawing to explain something relevant to the current discussion, but the architect could not physically reach the drawing from his side of the table. (As observed at a CIRS meeting, February 11, 2009 [8]).

Example 2

Digital meetings often have *drive*rs (media assistants or coordinators) who control most of the interaction on digital displays. The driver usually preloads the relevant information prior to the meeting. A specific information regarding parking was addressed in one observed meeting. The driver searched for the relevant information through folders of 2D digital drawings. It took 55 seconds to find the digital drawing and finally display the appropriate part. However, while the search for the document was on, other meeting participants pulled out the relevant paper-based plan and started discussing the issue. The length of time to locate the digital information meant that the paper-based information was used instead.

It has been observed during meetings that team members often need to switch back and forth between relevant sheets in order to refer to various diagrams and views. This process requires extensive use of cognitive memory and therefore these tasks using traditional tools can slow the work flow. Current digital technologies meant for meetings do not provide an easy way to perform this task, however tools that are meant to be used for the drafting process do provide ways for relatively easy transition between the relevant sheets. But such software tools do not provide quick and easy access and display of information along with collaborative features that are required during these meetings.

1.3 Mozaic

Based on the ethnographic work [8, 12, 52], recommended guidelines [12] and various workbench type setups [1,22, 48], we believe that digital displays and interactive applications can aid the meeting process by (1) improving access to information within design documents (2) improving access between design documents (3) make it easier for an meeting participant to control the information display. Fard *et al.* [12] studied design team meetings and recommended some guidelines for designing software and hardware to support effective communication between the team members. In our envisioned use, collaborative discussion of the team members involves gathering around a digital table (which mimics the traditional meeting setup) and using the displayed context on the table as a reference point to hold the conversations. This makes the tabletop displays work as a collaborative medium [8]. It has been seen that utility of information and quality of decision making is improved with the usage of interactive workspaces [14, 15] which makes us believe that tabletop displays can provide a significant advantage during meetings where the design teams use digital information.

Now that we have pointed out the importance of collaborative team meetings, use of artifacts and various bottlenecks during these meetings, how do we design an interface that improves access to information and thereby make documents faster to access?

Mozaic puts forward a preliminary design of a collaborative interface for exploration and investigation of the feasibility of using tabletop displays during digital team meetings. We seek to find out how users react to the various design features proposed in Mozaic and how they use those features, which may vary depending on the strategy employed. Mozaic attempts to improve access to information by incorporating some simple and intuitive interactive techniques such that it requires a small learning curve for users across all age groups and backgrounds. Building a simple yet functionally effective interface with simple interactions is challenging particularly because of the design team demographics in terms of age and experience with technology. Cavka *et al.* [8] hinted at various scenarios where bottlenecks arose from the fact that team members took longer (or put minimal effort) to understand the digital technology used at the meetings. In separate instances it was noticed that design coordination meetings often had architects or engineers chosen as *drivers* (Example 2) who were responsible for interacting with the displays and the software. Even though this type of "meeting dynamics" does not create a real bottleneck, it can at times slow down the workflow [52] especially when team members have to depend on the *driver* for relevant information. We strongly believe that well designed technology should support users with limited experience and therefore we focussed on building a simple and intuitive interface to encourage and engage design team members interacting with the interface. This allows the members to be less dependent on the driver during the meetings.

Mozaic does not intend to replace all paper in traditional meetings but it takes a first step towards investigating the feasibility of using digital tabletop displays at design meetings and begins to explore alternatives to the paper *stick set*. It aims to add more value to digital meetings by providing a shared workspace, making input possible from any location around a table, and allowing an easy mechanism to find documents.

This work is a follow up to the various requirements that were gathered during the studies and therefore it tries to conform to the standards that building design teams maintain. Even though our work focuses on the practices of the construction and architectural industry, this could potentially be generalized for other engineering areas where design team meetings are central to the industry.

This thesis puts forwards various design ideas specific to the domain problem, based on some generic tabletop design guidelines, followed by an exploratory study of these design ideas. Results indicate which design ideas are promising, along with some design decisions that need further refinement. The thesis also describes the rationale behind our design ideas and discusses the results of our evaluation in detail to ferret out some design ideas for the future.

1.4 Thesis Outline:

The remainder of this thesis is organised as follows:

Chapter 2: Highlights some of the related work and literature that forms the basis of this research.

Chapter 3: Discusses the various design ideas and considerations that led to the current design of Mozaic.

Chapter 4: This section puts forward the design of the user study conducted to evaluate and compare Mozaic with an interface that is currently used in the industry.

Chapter 5: This section presents the findings from the user study.

Chapter 6: Discusses various findings from the study and analyzes various interesting observations. This section also touches upon how Mozaic can incorporate these findings into its future versions.

Chapter 7: Concludes the thesis with key points from the results and discusses possible future research directions.

Chapter 2: Background Work

We group related work into three main categories:

1. **Ethnographies in Architecture and Construction Domains:**

   Here we discuss relevant facets of the work culture and existing practice in the architectural industry.

2. **Tabletops, Social Interaction and Meetings:**

   We identify relevant work that highlights the importance of tabletops in meeting scenarios. Such work also discusses group dynamics and various workspace interactions that suggest ways to increase productivity.

3. **Technology and Tools:**

   We discuss various tools and tabletop technology setups that inspired our design. We also highlight some meeting room setup guidelines that influenced our design and implementation decisions.

The following sections elaborate on these three categories.

2.1 Ethnographies in Architecture and Construction Domains

Design meetings involve extensive interaction with 2D and 3D CAD that constitute a stick set. 2D and 3D CAD provide different kinds of information which is very pertinent to the design team members. 3D CAD is useful to provide an overview and shape of an object being designed whereas its 2D counterparts provide more intricate and detailed information and enable simpler navigation [52]. It was been widely noticed and reported [8, 52] that design team members use a stick set as a center-piece of their conversation. It is important to have easy access to various representational artifacts during a design team meeting in order to coordinate work with others [16]. Since these meetings comprise members from varied disciplines (like architectural, mechanical, electrical), it is important that the stick set provides a common platform for all. The diagrams in a stick set form important “boundary objects” between disciplines and therefore allow the team members to engage in a discussion and communicate via visual representations [19]. Since the stick set is very important for design development and design coordination meetings, we realised that improving the interactivity between various construction project elements depicted on a stick set could potentially improve the meeting workflow.

Interactions with design information are critical to coordination during meetings [19]. It has been studied how interactions such as gestures were important to design information for engineering design [49, 50]. The studies pointed out that gestures towards artifacts are used to express concepts and ideas and communicate with other meeting subjects. Absence of attention-focusing interactions, such as gestures, affects the collaboration process as observed by Bly [4] and Robertson [41]. It was observed that gestures are most often deictic references to the information at hand [52], in order to communicate with others [30]. Eisenstein and Davis [10] observed that presence of a diagram during a meeting enhanced the communicative prowess of the members; 96% of the gestures were related to the diagram as compared to a meeting without a diagram. These deictic references help communicate the intent of the design and are more important at meetings than collaboratively creating design artifacts. Therefore these meetings primarily require quick and easy access to appropriate design drawings when required.

Visualization of information is an important aspect of team meetings. Cavka *et al.* [8] observed problems with visibility of information (as a group or individual) and classified this issue as a bottleneck. It has also been observed that side conversations are important to overall progress of meetings [52], so we think it is important to support such methods of communication between the team members. Therefore it was important for us to incorporate features in our interface design so that individuals or smaller groups of individuals can have their "own" display.

2.2 Tabletops, Social Interactions and Meetings

It is widely noticed that architectural and construction project meetings involve design team members positioning themselves around a table [8, 12, 52]. The table is used to lay out information in front of the design team members and enables members to hold discussions face-to-face. However in spite of these affordances, it has been observed that lack of visibility of information during meetings can disrupt the workflow. Digital displays also have challenges. Often digital meetings use wall displays, but it has been pointed out that that team members rarely walk up to the wall displays and prefer to point towards information on the wall displays remotely [8, 52]. This may be because of inefficiency of getting up and physically moving towards the display. Lack of remote interaction tools means that interaction with digital information was non-optimal in these observed digital meetings [8]. Moreover, wall displays are generally better for presentation-style interactions [43]. Therefore we believe that tabletop interfaces that mimic the traditional meetings may facilitate future meetings involving group discussion. Our use of tabletop displays is also supported by the fact that adults generally prefer to have face-to-face or corner seating arrangements during conversations [47]. Research shows that access to digital information on tabletops can take advantage of the experience people have with traditional tabletop collaboration [45]. People's interactions are more fluid and dynamic on tabletops [4, 49] and users are more physically animated while interacting on tabletops [45]. The visualization of information incorporates the notion of shared and private workspace along with individually embodied actions of the designers that facilitate the communication within the group [37]. These individual actions often involve intuitive gestures and use of deictic references [35, 17, 52] suggesting that tabletop displays may effectively support the mechanics of collaboration.

Furthermore, studies show that people are adept in transitioning between individual and group work [11, 29]. It is also important to have a universal input mechanism (accessible by every individual around the table) to support transitioning between activities on a tabletop [45]. This leads to smoother interaction with the system, especially when such collaborative meetings involve constant interaction with the underlying data.

Tory *et al.* [52] suggest that multi-user interactions may involve series of peripheral displays connected to a central display (perhaps a tabletop). In addition to that, subjects may find it more useful to use private displays of same design information as opposed to public displays [45]. This thesis however focuses on the aspect of public displays that can be used for discussions by design teams.

Luff *et al.* [28] pointed out that there is an abundant use of paper in computerized workplaces, with considerable redundancy between the informational content of the paper and the computers used in these environments. Design teams often use physical representations of the plan typically in the form of paper because paper by its very nature is tangible and easy to use for annotations as compared to its digital counterpart. But, information collected in terms of annotations often needs to be typed into digital form reprinted on paper. This creates a lot of overhead in terms of time and effort and often leads to unwanted financial and environmental expense [45]. Since nowadays, design documents are generated digitally, direct use of digital information in meetings can potentially be more time efficient and cost saving. Although the tangibility of paper based documents has some advantages, we believe that digital design drawings may outweigh the costs if some of the problems of accessibility can be reduced by better design.

2.3 Technology and Tools

There has been a conscious effort to design collaborative technology for meetings. For instance, the Stanford iRoom [23] has been used for design and construction meetings [14, 26].

Devices like the Tivoli electronic whiteboard, setups like i-LAND Roomware system, and the Dynamo multi-user surface contain digital elements that are desirable for computer-supported design development [22, 48, 38]. Livepaper [42] integrates paper with a tabletop display and projects information on the paper relevant to the topic displayed on the tabletop. Build-it [39] integrated multiple forms of physical (tangible bricks) and digital media and used computer vision based interaction technique for construction planning. Multi-disciplinary teams can work with this system which is geared towards integrating 3D CAD data displayed on a screen with corresponding 2D plans projected (from the top) on a table. The system uses the tangible bricks to manipulate information on the table and see the corresponding changes on the screen. This may be helpful for meetings involving designers and clients but it does not support multiple displays of sheets and quick navigation between 2D sheets.

Deskrama [32] is an interactive browser that uses a LCD display to browse 3D architectural designs when held over corresponding 2D schematics. The Luminous table [53] integrated digital information relevant to urban city planning projected on a tabletop display along with physical models. Augmented Surfaces [40] accommodate separate personal displays on tabletops. The Personal Digital Historian (PDH) tabletop system [46] introduces a unique method of providing users with distinct work areas and a system menu at the edges of the table allowing access to the system without disrupting the workflow. BEACH architecture of i-LAND and InteracTable [48] system allow pen based gestures on tabletops to perform certain frequent actions. Digital table setups like Digital Desk [55], Workbench and Drafting Table [5] integrate paper with digital displays, or project semi-immersive or virtual reality environments above tabletop displays. These applications and setups provide guidance about the design of collaborative meeting environments.

Mozaic is specifically geared towards improving the access to information during building design meetings by improving access to digital drawings; this aspect of the design makes

Mozaic different from all the previous work. Most of the above tools are either not designed specifically for our domain of interest, or solve very specialized interface problems. In contrast, Mozaic was designed to investigate the more common (perhaps even mundane) task of accessing the right document quickly at the right time in a design development meeting. Moziac incorporates some ideas from the above systems but implements the ideas for the purpose of querying and display in this particular context.

There has been some notable effort in integrating physical objects and developing tangible user interfaces (TUI) for architectural meeting scenarios. Most of these TUIs are designed to aid the process of collaborative design (design idea generation). Rarely do we see any TUI designed to aid the process of meetings devoted to design coordination, which requires supporting quick access to information rather than creative design activities. The meetings we focus on rarely involve creative design during the meetings, but rather focus on discussion about the design and financial aspects of the project. Some TUIs like Jump [51] and CAPRI [27] do focus on similar scenarios and involve integration of digital tabletops with paper and tangible blocks. However, working with such interfaces involves moving the tangible blocks (or objects) that often slow the process of transition from one architectural sheet to another, making them impractical for our scenario.

There has been a notable amount of work focussed on improving individual or collaborative design (or drafting) processes on tabletop displays. At the same time it is very evident that there has not been enough work to incorporate the idea of a *stick set* into digital meetings that will allow rapid access to information and aid the process of discussion. Mozaic aims to mimic the some facilities (like being a repository of information and display documents) provided by a *stick set* with added information access and presentation elements to improve the workflow and information access during design team meetings.

Chapter 3: Interface Design

Mozaic applies various design guidelines for tabletop interface design [45] along with guidelines proposed by Fard *et al.* [12] to allow the stakeholders of a construction project to smoothly and interactively interact with the digital design documents that primarily consist of 2D schematics of the project (plus static 3D views). In other words, the focus of the design is to aid the team members with navigational tasks and improve the information accessibility. Mozaic incorporates four main design ideas:

- Tile based interface: It allows side-by-side display of documents.
- Pop-up menu: This allows universal access as opposed to fixed menus.
- Filter for query: Allows filter based searching for documents from a large document collection.
- Related-View of sheets: Allows smooth display of related diagrams on related sheets through Detail tags.

Our design ideas and considerations stem from our understanding of the functionality of the stick set, discussion with a construction engineer and from previous ethnographic work. As part of gathering requirements from previous ethnographic work we observed two recorded design team meeting videos. These recordings depicted the use of digital displays for displaying digital information besides the use of paper based plans. We focused on observing how the meetings were conducted and how information was navigated during these meetings.

We focus on supporting navigation among documents, because we believe interactions with design information in meetings are primarily navigational (except for gestural references that do not require computer action). We begin by defining the tasks the interface needed to support. To understand such tasks, let’s look at few scenarios:

Scenario 1: Compare Tasks

"Jenn and Tom are two stakeholders of a construction meeting. Jenn is concerned about whether newly modified electrical plans prepared by Tom's group will interfere with the construction of an "I" beam on the ceiling of Room A. Therefore she needs to display the Reflected Ceiling Plan of Room A as well as Electrical Plans for Room A and compare them."

The above scenario reflects the need of stakeholders to search for sheets and display them for visual comparison. Construction project meetings require quick and frequent access to information; therefore it is essential that the meeting members can find relevant documents quickly. Searching for information and being able to find it includes the action of displaying the information in front of the person concerned. Designing an interface that allows the users to do such a task at ease was the primary design consideration for us.

Scenario 2: Sheet Manipulation

"Jenn and Tom are positioned beside each other around a table during a meeting with digital setup. Jenn needs get a better view of the 3D model that Tom is talking about. She also needs to compare this 3D model with a 2D floor plan but certain text on the 2D floor plan is not rendered properly and therefore she needs to magnify it. "

This scenario reflects a task that involves actions to get a "better view" of an item displayed on the screen. Cavka *et al.* [8] observed that team members often used A4 sized representations of a sheet. Digital media offers functions to perform magnification or zooming for a better view of the document. We considered adding such functionality to Mozaic.

Scenario 3: Retrieving Detailed View

"Jenn and Tom are discussing the Ground Floor Plan (A-101) of a building that is laid out in front of them. They realize that they need to refer to the drawing B2 on the sheet A-701 that has the detailed view of the exit stairs. They start to search for the sheet A-701 by searching for the page number from the index of the stick set , find the sheet and then look for the drawing B2."

Design team meetings often involve working with multiple sheets. It is very common to find that a detailed view of some object, such as a staircase, is located on a different sheet. Team members often switch back and forth between these "related" drawings to get a sense of the schematic that is laid out in front of them. This is a fairly common task and therefore our design decision with the software had to include a feature that will enable this action to be performed smoothly. With the paper stick set, these tasks involve a lot of recollection of the numbering scheme and reference to the index of sheets. This can be a lengthy process as described in the scenario. Tory *et al.* [52] also pointed out that the stakeholders often place their fingers between the sheets, or find some other cognitive means to bookmark the related sheets. We realized the need to create a smooth and effective way to switch back and forth between the related sheets. This led us to create an interactive action to let the users switch back and forth between related sheets or display them side-by-side.

These tasks constituted the central idea behind Mozaic's design and helped us shape our own design goals that are highlighted below.

3.1 Design Goals:

Our design goals for the interface can broadly be divided into two categories.

1) **Tasks Supported**: We outlined various tasks that we intended to support:

   i. Query Task: An easy and intuitive way to query for a specific sheet or view.

   ii. Display Task: An easy way to display a sheet on the tabletop.

iii. Magnification Task: An easy and intuitive way to zoom in and out of displayed sheets.

iv. Within-sheet Navigation Task: A way to navigate through a sheet such that every corner of a sheet is accessible to the user.

v. Sheet Share Task: An easy way to pass any sheet around the table for collaboration.

vi. Linked or Related View task: An easy and intuitive way to switch back and forth between related sheets.

vii. Multi-view Task: An easy way to display multiple sheets on the tabletop. We also wanted to incorporate the idea of having multiple views of the same sheet.

2) **Interactions Supported:** One of our design goals was to allow users to easily interact with the data without the expense of learning new interaction techniques, since design team members are often hesitant to learn new technologies [8].

i. Mirror interactions of familiar technology: We decided to reduce the learning curve of team members by introducing "single-tap" and "double-tap" interaction techniques that mimic the standard "single-click" and "double-click" interaction on desktop systems. Any menu on the interface can be activated by double-tapping on the screen and any selection on the menu can be activated by single-tapping on the selected item.

ii. Intuitive controls: We wanted to design an easy and effective way for the users to control the number of sheets being displayed on the screen. We also wanted to incorporate features that would let the users easily control the size (and resolution) of the displayed sheets. We accomplish this via a Tile-based interface.

iii. Universal Menu Access: Since driver is the most critical interactor at the design team meetings we wanted to allow him/her position him/herself anywhere around the table. We also wanted to encourage other team members to interact with the system whenever they needed to. We believe that this flexibility would allow smooth transitioning of the system's control between the team members without undermining the importance of the driver. Therefore, our design provides access to all functionality via a popup menu that can be invoked anywhere on the screen. Further, to make interaction faster we decided to make the menu circular in design.

3.2 Design Assumptions:

Based on previous ethnographic studies we decided to build the tabletop interface based on certain assumptions. These assumptions were:

1) The design team members will position themselves around the tabletop during design team meetings.
2) These meetings will usually have "drivers" [8, 52] who are in-charge of the navigation tasks on the digital displays. This means that two or more users will rarely interact at the same time, so multi-touch capability is not a primary concern, and evaluation of the design ideas can focus on the driver.

3.3 Design Guidelines:

We considered these underlying design guidelines while designing Mozaic. These guidelines were primarily influenced by guidelines proposed by Scott et al. [45] and Fard et al. [12]. They are:

1) Shared information should be visible to all group members.
2) Support individual activities without interfering with group activities.
3) Support subgroup activities without interfering with group activities.
4) Provide a universal input mechanism (accessible to all users).
5) Support users who have limited experience with technology.

6) Enable side-by-side comparison of design documents.

3.4 Implementation:

Mozaic was programmed in C# using Microsoft Visual Studio 2008 and.Net Framework 3.5. The computer used for implementation operated on Intel® Core 2 Quad CPU Q6600 @ 2.40 GHz. It had a 2 Gb memory and a 32 bit operating system (Windows XP). The system was further supported with two ATI Radeon HD5800 series graphics cards. The table top display that was used to run the study comprised of 4 HD rear projectors (Epson Powerlite Pro Cinema 1080 UB) each with a resolution of 1920 x 1080 pixels, 60Hz) projected on a camera-based Smart flat panel display (DViT screen). The display was capable of accepting a maximum of 2 inputs at any point of time; however, due to limitations of the software toolkits used, the software could only accept one input.

Before we take a detailed look at the prototype we need to point out that we are concerned with displaying static digital architectural sheets on a table top surface and therefore we chose to work with (.) jpeg images of the architectural sheets. Our sample data was stored as an Autodesk Revit Architecture 2009 file (.rvt); we therefore had to extract the images in JPEG format from this .rvt file by using Autodesk Revit Architecture 2009.

3.5 Overview of the Design of Mozaic:

In this section we describe the various functions and interactions of the Mozaic interface as shown in Figure 2. We improved the design of Mozaic over several iterations and four pilot studies before the current design, as described in Appendix E. We structure this section by providing an in-depth look at the various tools associated with the prototype and then talk about how interactions with these tools aid the design team meeting tasks. The layout of the tools and the order of discussion follow the overall organisational structure of the software as shown below.

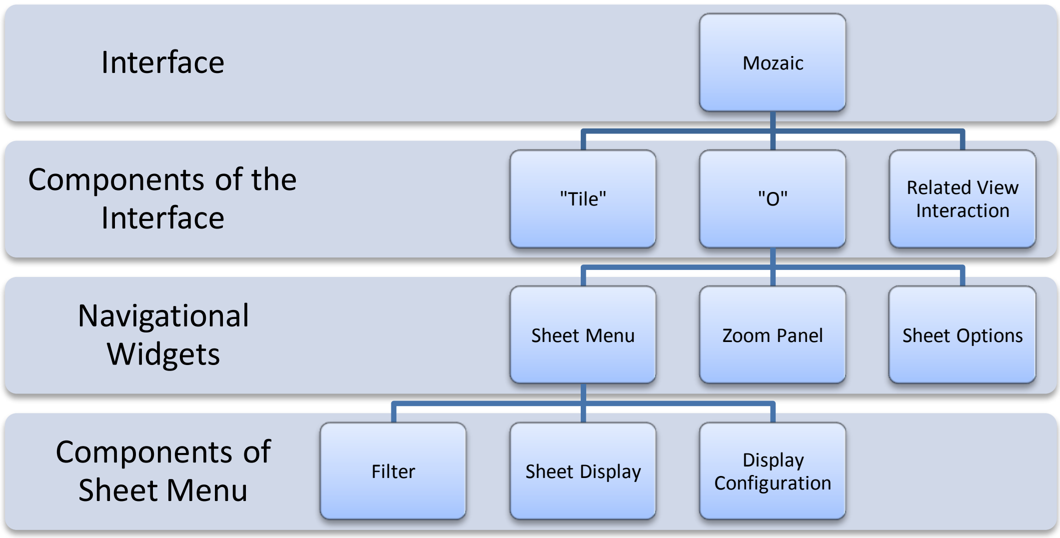

Figure 2. Overview of the components of the Mozaic interface

The Mozaic interface encompasses the design idea of having a Tile-based display where a “Tile” is a container that holds a digital image of a sheet, and multiple tiles can be visible simultaneously. A Tile based display allows multiple views of sheets and sheets can be positioned side-by-side during tasks that require comparison.

Studies have shown that high-resolution tiled displays benefit basic visualization and navigation tasks [2]. Ball *et al.* [2] further pointed out that high-resolution tiled displays involve physical interaction with data thereby reducing repetition and increasing confidence. Park *et al.* [36] emphasized on the importance of tiled wall displays and how such displays can engage group members into intensely collaborative team meetings by increasing group awareness and collaboration. This made us incorporate the idea of a Tile based display interface for better visualization and navigation facilitated by simple interaction techniques. A Tile based display does not occlude the displayed data as opposed to floating overlapped windows (assuming each window contains one sheet) and aims to aid complex comparison tasks.

The interface can be accessed from anywhere on the tabletop through a circular popup menu [21] tool called “O”, which resembles the letter “O” and hence the name. Item selection on a circular menu is an average of 15% faster than on a list menu [7] and this led to the rationale behind the design of “O”. “O” allows universal access (from anywhere around the table) and can be activated or deactivated as needed. The third main design idea, “Related-View Interaction” links related sheets and views amongst themselves. This allows a smoother interaction and transition between the related sheets and reduces overhead in terms of memory recall, index searching and bookmarking.

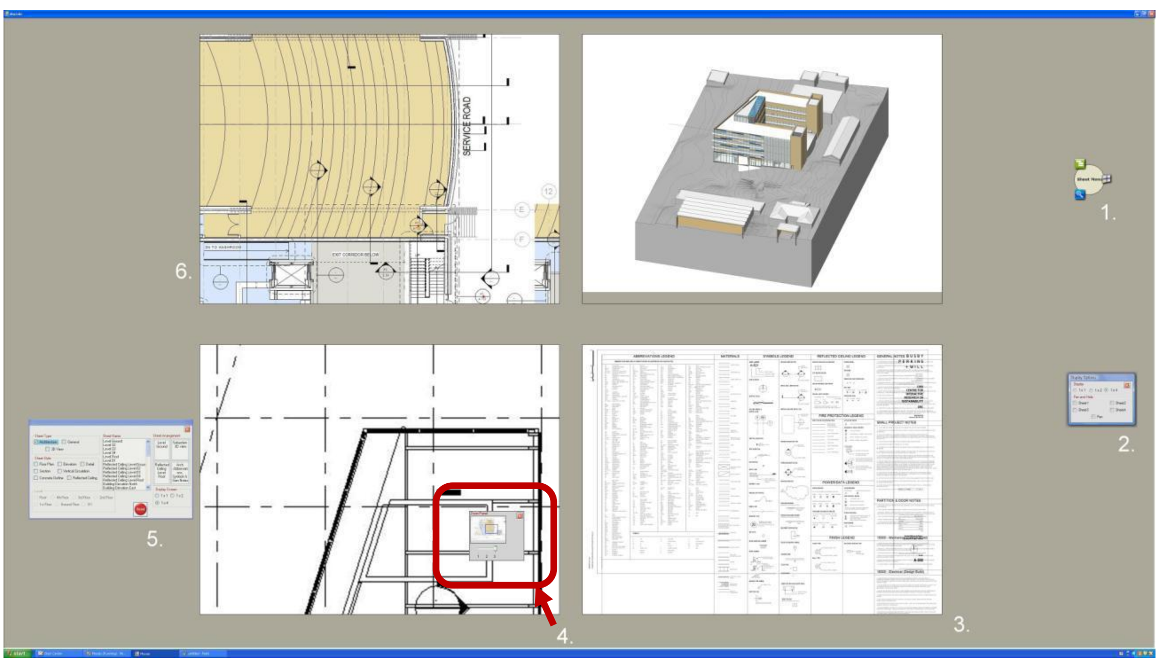

Figure 3. Screenshot of Moziac interface (1 x 4 setup). 1. “O”. 2. Display Options. 3. Tile. 4.Zoom Window. 5. Sheet Menu. 6. A Tile displaying a magnified sheet.

Let us examine the three main parts of Mozaic in detail.

1. **Tile**: A "Tile"[Figure 3] is a picture box that displays the architectural sheets in form of images. In day-to-day life analogy, a "Tile" can be imagined as a picture frame that holds pictures. The default setup of the Mozaic interface allows a maximum of four tiles on the screen. Each Tile during this setup has a resolution of 1200 x 900 pixels. In other words, the tiles provide an overview of the sheets, which are otherwise 3239 x 2159 pixels in size. Note that the interface allows a maximum of four tiles on the screen at all times. We assume that no more than 4 sheets would be needed at a time, and this conveniently matched with the hardware setup of the table. We call this display setup a 1 x 4 setup (i.e. 1 screen containing 4 tiles). However, the display can be modified to a 1 x 2 (i.e. 1 screen containing 2 tiles, each 1200 x 900 pixel) or 1 x 1 setup (1 screen, 1 Tile with a 3840 x 2160 pixel resolution).

Figure 4. "O". 1. Sheet Menu icon 2.Display area for name of the selected icon 3. Display Configuration Menu icon. 4. Zoom Panel icon.

2. **"O"**: "O" [Figure 4] is a circular context menu used to display the tools that a user can use to work with Mozaic. "O" can be activated by double tapping anywhere on the screen. This allows any user gathered around a table to interact with the system controls. A double tap interaction is analogous to "double-click" interaction on standard desktop

systems. The context menu starts up with a quick 10 millisecond "entry" animation of the objects listed on it and then it comes to a full stop until an option has been selected. After an option has been selected the chosen option is displayed as text at the center of the circular menu before the menu closes with a 10 millisecond "exit" animation. The three tool options that "O" puts forward are Sheet Menu, Zoom Panel and the Sheet Options Menu.

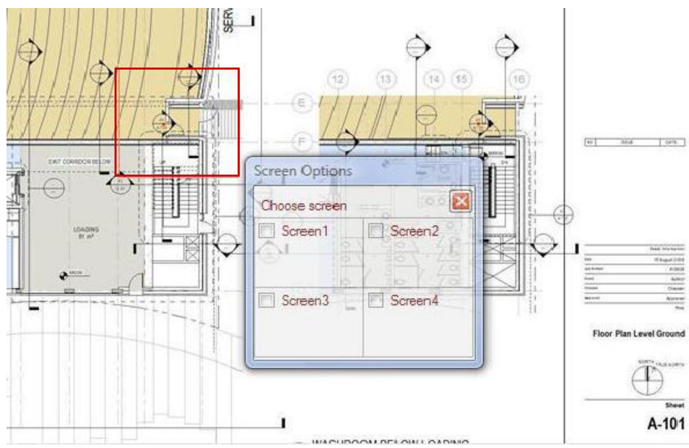

Figure 5. Related-View Interaction. A detail tag selection shown by a red rectangle leading to a Screen Options pop-up window.

3. **Related-View Interaction**: Mozaic allows users to interactively switch between drawings (if available) on a displayed sheet [Figure 5, Figure 6]. The user can select the "detail tag" [Figure 15. Appendix C] on the displayed sheet by dragging a finger across the "detail tag" on the screen diagonally from the top left corner to the bottom right corner. This action draws a red rectangular box around the point. This rectangular box "binds" the location on the image and queries for the related drawing / view. If the related drawing is available, a small window pops-up on the screen near the "detail tag". This "Screen Options" window represents the tiles on the screen and is divided into four quadrants representing four available tiles. Each quadrant has a checkbox. Selecting a

checkbox displays the related view/ drawing on the tile. Un-checking the box reverts to the previous state of the tile. On our prototype we pre-processed the data and linked only a few sheets with their related drawings and views, as needed for our user study. The points of interest connected to related data were marked with a red dot whereas the ones where data was not available were left in their original state.

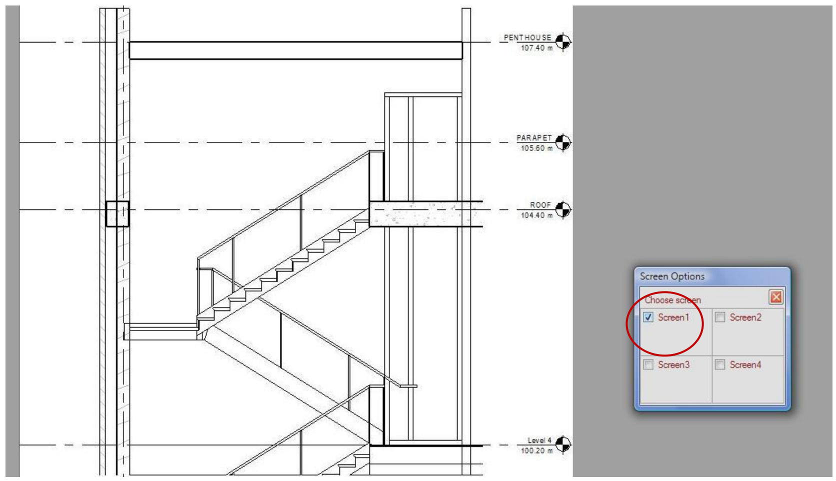

Figure 6. Results of selecting screen 1(shown in a red circle) from Screen Options menu after a detail tag is selected.

Therefore a user can visually know whether related data is available for a certain "detail tag". If an unconnected detail tag is selected, Mozaic returns a pop up stating unavailability of the data. Related-view interaction provides a logical and intuitive way to switch between multiple related drawings, saving time for accessing related sheets.

3.6 Detailed Look at Mozaic

Apart from the three main parts listed above, Mozaic is comprised of widgets that can be accessed through "O". These widgets (as mentioned earlier) are the Sheet Menu, Zoom Panel and Sheet Options Menu. Let's take a detailed look at these.

3.7 Accessible Widgets through "O"

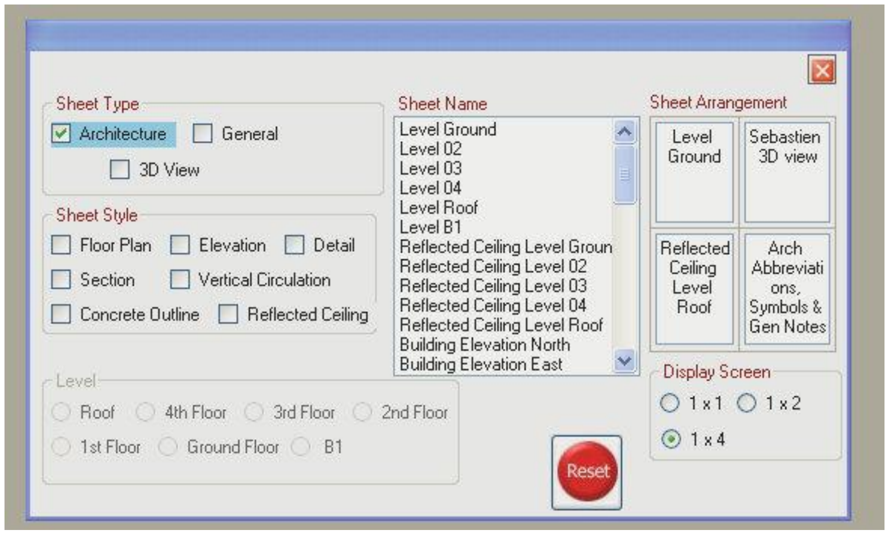

Figure 7. Sheet Menu.

1. **Sheet Menu**: The "Sheet Menu" [Figure 7] is a filter that allows the users to query for sheets that they would normally use during a meeting. The filter is built using a Windows form that pops-up every time the "Sheet Menu" option is selected from "O". It is important to remember that once selections are made on the Sheet Menu, they are still active when the menu is closed. In order to reset the menu to its default form, the user needs to click on the Reset button on the menu. This resets the whole menu and the displays on the Tiles as well. The sheet menu can broadly be divided into three main parts – Filter, Sheet Display and Display Configuration. The Filter was designed with a consideration that Architectural 2D sheets, 3D static models and views and Sheet Indexes and Abbreviations are different from each other. In other words, the basic premise of the design was to demarcate the various types of sheets according to their type. The Sheet

Display is concerned with displaying the result of the query selected from the filter. The Display Configuration takes care of the Tile display on the screen and their pre-defined resolution. We will take a detailed look at the design of the Filter, Sheet Display and Display Configuration after we discuss the other widgets available through “O”.

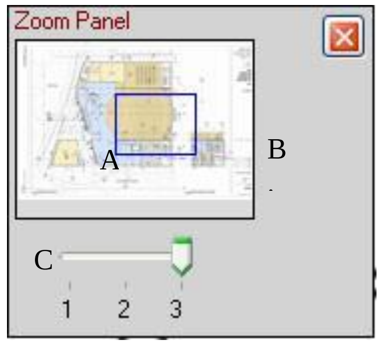

Figure 8. Zoom Panel. (A) Blue rectangular box. (B) Zoom Window. (C) Zoom Slider.

2. **Zoom Panel**: This is the second option that a user can access through “O”. This function is activated when the Zoom option (Zoom icon) is selected from “O”. In order to activate the zoom window [Figure 8, Figure 9] “O” needs to be activated on the image that needs to be magnified or de-magnified. It needs to be noted here that the zoom tool will only be active for a displayed image on a tile. The zoom panel contains a 120 x 90 pixel representation (called Zoom Window) of the associated tile’s image, and a zoom slider. The slider consists of three discreet levels of zooming 1x (100% of the image), 2x (200% of the image) and 3x (300% of the image). Once the zoom panel is activated over a specific Tile (containing an image) other tiles can also be selected just by tapping on them once. This interaction tool is aimed to smoothly transition between displayed images on multiple tiles. This interaction allows a faster transition simply because it does not involve activating the zoom window every time the user needs to zoom in an out of an image. It is to be noted here that zoom function can only work with one Tile at a time. Let’s look at an example to further describe the feature.

Example: "Jenn wants to zoom-in on the images on Tile1 and Tile2, therefore she activates the zoom panel by selecting it from "O" after double tapping on Tile1. Once the zoom panel is displayed, it shows an overview of the image on Tile1 on the zoom window. Jenn taps on Tile2 to 'select' the image and the zoom window displays the image on Tile2."

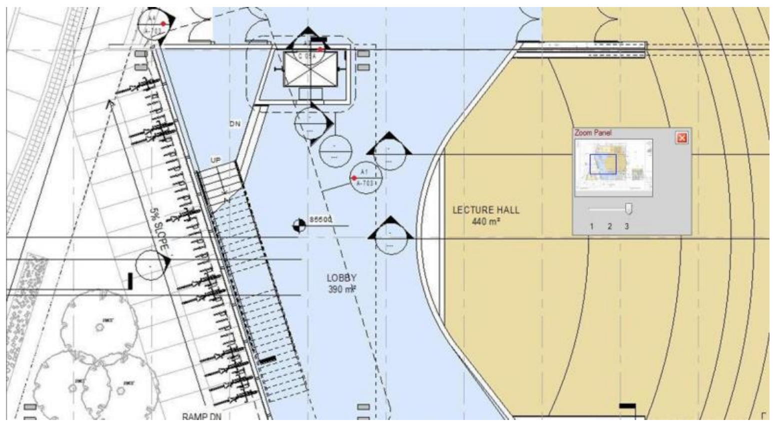

Figure 9. Screenshot displaying a zoom panel and a Tile displayed a magnified sheet bounded by a blue rectangular box on the zoom window.

The zoom window can also be used to navigate within the displayed sheet. When the magnification on the slider is not set to 1, a small blue colored rectangular box is displayed within the window. This blue box can be used to move around within the bounded limit of the zoom window which results in "within-sheet" navigation (a pan action).

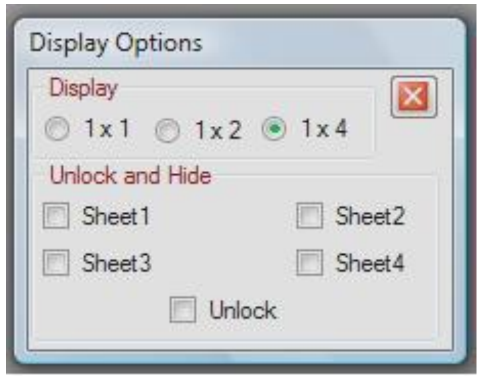

Figure 10. Display Options showing various filters.

3. **Display Options**: Display Options [Figure 10] is the third option that a user can use from “O”. This is activated when the user selects the sheet options button from the menu. This window deals with the various sheet manipulation actions that users might need during a meeting. This window primarily consists of three main parts – (a**)** Hide Sheet, (b) Pan Function (c) Display Configuration

   The **Hide Sheet** function allows the users to hide and unhide sheets in 1 x 4 or 1 x 2 display configurations. This functionality is designed for situations during a team meeting when some sheets can be “bookmarked” for later use. Often there are situations during meetings when the users may want to “bookmark” a specific sheet for future use (in meeting timeline). Therefore they might want to have the sheet readily available (instead of querying for the sheet) but not display it on the screen when something else is being discussed. With the help of the Hide function, the users can “Hide” a sheet from immediate use and “Unhide” it when required. This function can be activated by clicking on the checkbox assigned for a particular Tile. In other words, each Tile has its own checkbox which can be “checked” or “un-checked” thereby hiding or displaying the Tile.

   The **Unlock Function** allows sheets to be passed around a tabletop display during design team meetings where multiple users share sheets. It can be activated by selecting the checkbox associated with it. On selecting it all tiles are “free” of their static position and therefore they can be moved around the table when required. Un-checking the Unlock option stops the tiles from being “free”. It is important to note here that the tiles do not go back to their original positions on un-checking the Unlock option. This lets a user to stand at one side of the table and smoothly work with the tiles as required. The tiles can be reverted back to their own default position by re-selecting 1 x 4 display option from the Display Configuration menu. It also needs to be noted that the zoom function and “within the sheet pan” function work when this Unlock function is active. This interaction is intended so that users can control magnification of the Tiles even when the sheets are passed around the table. This design also allows the driver to present the data to other users who are positioned farther away from the driver.

The **Display Configuration** is similar to the display configuration on the Sheet Menu (discussed later). It can be used to reset the Tile positions on the screen after Unlock Function has been used.

3.8 Design of Sheet Menu

Now that we have had a detailed look at various widgets that can be accessed through the “O”, these next few paragraphs discuss various parts of the Sheet Menu in detail. The Sheet Menu comprises of a Filter, Sheet Display and Display Configuration.

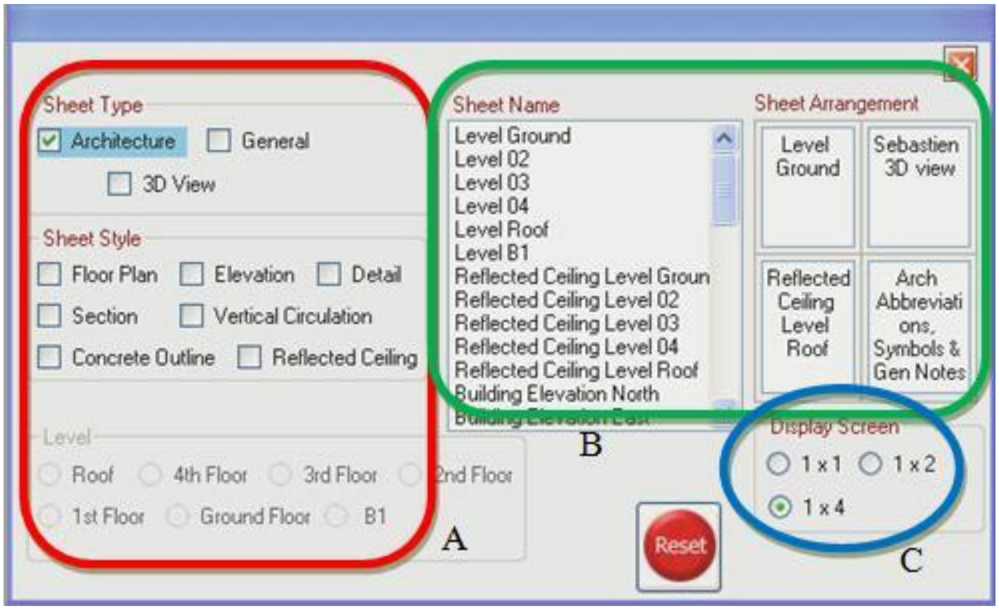

Figure 11. Parts of Sheet Menu. (A) Filter. (B) Sheet Display. (C) Display Configuration.

3.8.1 Filter:

The Filter [Figure 11] is the section of the Sheet Menu that is used to query for a sheet. It consists of numerous options of checkboxes and radio buttons. The design rationale behind the Filter is to allow users to search for documents among large collection of documents by selecting the type, style and floor level depicted on the sheet. The filter is designed so that it develops a query as the options are being selected. The Filter can be primarily divided into three main parts – Sheet Type, Sheet Style and Floor Level.

1. **Sheet Type**: It is the primary block of the Filter. It is used to broadly categorize the repository of sheets into three main types – 2D architectural sheets, static 3D views and General index sheets. These are comprised of three different checkboxes. Selecting each checkbox queries for all the sheets in that category and fills up the **Sheet Listbox**. Sheet Listbox is the list that displays the name of all the sheets present depending on the filter selection (discussed later in detail). Selecting all the

checkboxes together selects all the sheets present in the repository. Un-checking the checkboxes deselects the query and therefore data associated with the un-checked option is not displayed on the Sheet Listbox.

2. **Sheet Style**: 2D Architectural sheets are categorized according to the type of spatial arrangement they represent. This part of the filter allows users to narrow down the Sheet Type according to (a) Floor Plan (b) Elevation (c) Section (d) Detail (e) Vertical Circulation (Stairs) (f) Reflected Ceiling (g) Concrete Outline. For example, if Tom needs to find and display a floor plan on the Sheet Listbox from the group of architectural sheets, he needs to select the "Architecture" checkbox from the Sheet Type category and then select the "Floor Plan" from the Sheet Style category. These sets of filters are disabled by default. These only get activated when the "Architecture" checkbox is selected from the Sheet Type category. It is important to note that only 2D architectural schematics can be subdivided according to Sheet Style and Floor Levels. It also needs to be noted that multiple checkboxes cannot be selected together on this filter category. Since selecting multiple checkboxes forms a long list of queried items (especially when there are a long list of sheets associated to those categories), it takes a longer time to look for any particular item from a long list. Therefore we chose to allow the users to choose sheet style options one at a time.

3. **Floor Level**: This represents a set of radio buttons that is used to further narrow down the search in terms of floor levels in the building. For example, if Tom wants to find and display 2D_Floor Plan of the fourth floor of a building then he needs to select "Architecture" from Sheet Type, "Floor Plan" from Sheet Style and "4th Floor" from Floor Level. These filters are disabled by default and get enabled only when certain Sheet Style options are selected. Not all architectural schematics were associated with levels in our sample data; therefore, enabling the Level filter depends

on whether floor information for certain types of images are present. Our sample data had floor level information for Floor Plan, Reflected Ceiling and Details sheet types. Therefore the Floor Level filter was activated only when one of these was selected.

3.8.2 Sheet Display:

It is comprised of the Sheet Listbox and the Sheet Display Quadrants which are associated with the task of displaying the queried sheets. The following sections discuss these two in detail.

1. **Sheet Listbox**: The Sheet Listbox lists the items from the repository as the options on the filter are being selected. In order to display the sheets on the tiles, the user needs to select one sheet at a time and then drag and drop the sheet onto the Sheet Display Quadrant.
2. **Sheet Display Quadrant**: This replicates the ordering of the Tiles on the screen and consists of a grid separated into 4 quadrants. Each quadrant contains a textbox that displays the name of the sheet displayed on the Tile associated with it. It allows a user to display multiple copies of any sheet on the screen. The user can drag and drop the sheet name shown on a textbox onto other text boxes.

   The quadrants are associated with a Priority Level. This pre-defined Priority Level determines the flexibility with the resolution and display options. In other words a Tile with highest level of priority (Level 1) is most flexible with its display resolution. There are three such levels ranging from Level 1 (highest priority) to Level 3 (lowest priority). It is important to understand that these levels are pre-set in this iteration of the interface and therefore the user is unable to change these Level settings. This can be better explained in the Display Configuration section below. The figure below shows the quadrant to Tile relation and the Priority Levels.

Tile1 Quadrant 1 Priority Level 1	Tile2 Quadrant 2 Priority Level 2
Tile3 Quadrant 3 Priority Level 3	Tile4 Quadrant 4 Priority Level 3

Table 1. Arrangement of Tiles and corresponding Sheet Display Quadrants.

3.8.3 Display Configuration:

Study [8] shows that different tasks require different sheet arrangements, requiring flexibility in terms of how the sheets are displayed. The display configuration group box allows the user to choose the resolution of the sheet and number of sheets being displayed. A user can choose from 1 x 4, 1 x 2 and 1 x 1 display options, which display 4, 2, and 1 tiles respectively. 1 x 1 option allows the user to look at a single sheet at full resolution when a detailed view is needed. We believe that 1 x 4 and 1 x 2 display options are needed usually during comparison tasks involving an overview of the sheet. It was also pointed out by Cavka *et al.* [8] that team members often used A4 sized representations of architectural sheet as they can be easily navigated. The following table shows the resolution; number of tiles displayed and number of quadrants that are activated on the Sheet Display menu.

Display Option	No. of active Tiles	No. of active Quadrants	Priority Levels	Display Resolution Of Each Image (in pixels)
1 x 4	4	4	All Levels	1200 x 900
1 x 2	2	2	1 & 2	1200 x 900
1 x 1	1	1	1	3840 x 2160

Table 2. Display characteristics of Tiles

3.9 Example Scenarios

To help us better understand how the above mentioned parts work during various tasks we put forward an example scenario and underline the interactions involved in the scenario.

"Jenn and Tom want to display sheets Level Ground Floor Plan and Building Elevation East on Tile1 and Tile2 (both closer to their position) respectively for some comparison task. The task will involve using the zoom panel. Steve on the other hand wants a separate copy of Ground Floor Plan on Tile3 and wants to talk to Mike about the exit stairs on the East side of the building. Mike wants to display the 3D model of the building on Tile 4. "

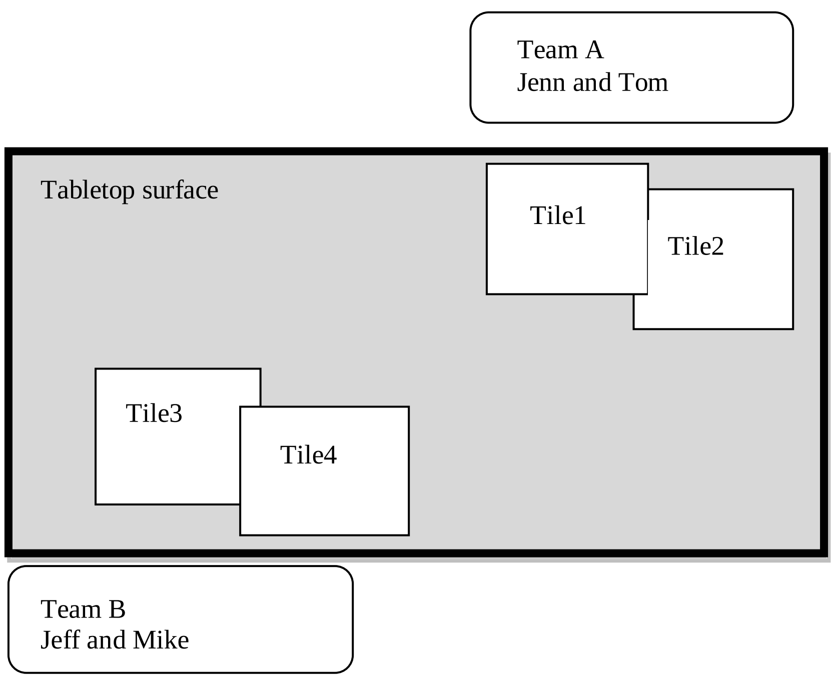

Figure 12. Scenario depicting 2 teams at work with Mozaic.

Jenn and Tom (assuming Jenn is the driver) :

Jenn double taps on the screen of the table every time she wants to bring up "O" and selects Sheet Menu or Zoom function. The first time that she brings up the Sheet Menu, she selects "Architecture" from Sheet Type, "Floor Plan" from Sheet Style and "4th" floor from Floor Level. Every time she selects a checkbox, the Sheet Listbox gets updated with new results, ultimately displaying <u>Level Ground Floor Plan</u>. She selects the displayed sheet name and drags it onto the "Sheet Quadrant1" (representing Tile1) and drops the sheet. Once the sheet is dropped onto the Quadrant1, the text box on quadrant displays the Sheet name and the Tile1 on the table surface displays the image of the sheet. She goes back to the Sheet Menu (already up on display) and selects the "Building Elevation" selection. On selection, this pre-existing Floor Plan selection is unchecked and so is the Floor Level selection, as building elevations do not incorporate floor levels. She finds that this new query results in a list of Elevation sheets in the Listbox. She selects the required sheet i.e. Building Elevation East and then drags and drops on to Quadrant 2 of the Sheet Display Menu. This results in displaying the sheet Building Elevation East on Tile2. Since Jenn's task involves comparison, she decides to bring up the Zoom Panel that might aid her work. She double taps on Tile1 to activate "O" and select the Zoom Panel option from it. Once the Zoom Panel is active it shows the image on Tile1 on the Zoom Window. On moving the slider the image on Tile1 magnifies and the blue rectangular box on the Zoom Window decreases its area proportionally. Jenn then moves the blue box around the Zoom Window and locates the section of the Floor plan she wants to compare and discuss. The overview of the sheet on the Zoom Window helps Jenn to locate her point of interest on the sheet.

Steve and Mike's scenario (Steve is the driver):

Steve and Mike are at the corner of the table and they decide to carry on their own conversation such that Jenn and Tom are not bothered. Steve is aware that Jenn is using the sheet for Ground

Floor Plan. Once he brings up the Sheet Menu (he double taps and selects Sheet Menu which already displays Jenn's selection) he drags the text from Quadrant 1 on the Sheet Display Menu to Quadrant 3. This creates a copy of the text on Quadrant 3 resulting in the display of the Ground Floor Plan on Tile3. Mike asks Steve to bring up the 3D model of the building on Tile4. Steve un-checks the Architecture checkbox from Sheet Type thus resetting Sheet Style and Floor Level. He selects 3D views, upon which all the listed 3D views and static models are listed on the Listbox. He selects the required model and drags and drops it onto the 4th quadrant of the Sheet Display Menu. This results in displaying the 3D Model on Tile4. Steve realizes that he needs to display the related drawing for the exit stairs, and therefore he drags his finger diagonally around the "detail tag" associated with the exit stairs on the Ground Floor plan. This results in drawing of a red rectangle (with no fill) around the tag. On lifting his fingers from the table a small pop up window is displayed that shows a quadrant view of the tiles. He selects Tile3 (Quadrant 3) to display his related view. Upon selection, the related view of the stairs appear on Tile3 and the pop-up window is still displayed. To switch back and forth between The Ground Floor Plan and the related view, Steve un-checks and checks the selection box on the quadrant 3 respectively. This helps Both Steve and Mike to compare and discuss the Floor plan, related drawing of the exit stairs and the 3D model.

Chapter 4: Evaluation

We conducted a usability study to explore the effectiveness of various design features in Moziac and how people would make use of them. We kept in mind that the effectiveness of design ideas may vary depending on user strategy. This chapter describes the steps and methods we undertook to evaluate Mozaic.

To help assess the value of our design ideas we were interested to explore some alternate interface design ideas as a point of comparison. We therefore decided to compare Mozaic (which was specifically designed for tabletop) with a software tool that was not designed using tabletop design guidelines and incorporated some alternative design features. Scott *et al.* [45] points out that evaluating collaborative interface for tabletop displays can benefit from control conditions involving traditional media and setup. Tory *et al.* [52] pointed out that digital meetings often involved data in the form of 2D AutoCAD drawing files and PDF documents, viewed using an Autodesk product or a PDF file reader like Adobe Acrobat Reader 8.0. We chose Acrobat because it was observed in design meetings in practice and encompassed alternatives to our three major design ideas as shown in table 3.

Design of Mozaic	Design of Acrobat
Pop-up Sheet List	Fixed linear sheet list
Filter based query	Linear list
Tile based display allowing 1-4 sheets at a time	Singular display displaying 1 sheet at a time

Table 3. Comparative designs of Mozaic and Acrobat

Since our research question aimed to find the feasibility of using digital tabletop displays to improve the workflow during team meetings, we decided to use both interfaces on a tabletop.

We designed two similar sets of tasks that the users would have to complete by using both interfaces. They were timed while completing the tasks but the main focus was on observation of usability problems and how the design features were used. In the following sections we refer to Adobe Acrobat Reader 8.0 as simply Acrobat. Describing the Acrobat interface in detail is beyond the scope of this thesis; however we will cite various features and design of Acrobat when and where relevant.

4.1 Study Design:

Our study was designed to examine tasks of navigation through data, figure matching and correlating 2D elements of a drawing to 3D elements. These basic tasks are commonly performed during meetings and form an integral part of these meetings as pointed out in various ethnographic studies [8, 52]. The tasks were not complicated and were expected to be completed with minimal training in basic architectural and construction schematics and nomenclature.

Tory *et al.* [52] pointed out that digital team meetings often had a driver who was responsible for navigational operations with the sheets. This showed us that even though the meetings were highly collaborative in nature, interaction with the data was usually done by one person. Therefore in our study we examined interactions of one participant at a time. In other words, the study did not focus on evaluating the collaborative aspect of our tool; rather it was designed to find out how a user can navigate through the interface while performing various tasks on it. In the following sections we describe the various elements of the study in detail.

4.1.1 Subjects:

We focussed on recruiting subjects from Engineering and Computer Science. We recruited sixteen subjects (12 males and 4 females, 1 from Mechanical Engineering, 6 from Electrical Engineering, 2 from Computer Engineering and 7 from Computer Science) for the study. Two subjects had prior experience in the construction industry. The rest had some familiarity and understanding of simple building layouts. All the subjects had some level of familiarity with touch screen displays.

The subjects were remunerated with $15 for their participation. The subjects ranged from 21 to 30 years of age. Fifteen out of sixteen subjects were right handed.

4.1.2 Data:

Design of a university research building was used as our data. Data was in the form of Autodesk Revit file (.) rvt. We exported the 2D and the 3D schematics from this (.) rvt file as static (.) jpeg image files. These images were representations of the sheets of the original stick set that was used during the construction project. There were 35 images, each 3239 x 2159 pixels in dimension. The images were stored in a folder and a tab delimited file was created for the purpose of database query for Mozaic. A PDF file was created with these images to be used by Acrobat for the study.

4.1.3 Tasks:

We compared the user's ability to navigate between architectural sheets in Mozaic versus Acrobat. We wanted to observe how various low-level navigational tasks could be completed on both interfaces. We primarily observed users while they were performing the tasks, but we also calculated the time taken to complete each task [see Appendix D for timing results]. The usability study was comprised of an Observation phase followed by an interview. The interview focused on collecting subjects' feedback about both software tools and the challenges they faced during the course of the study. Various navigational operations and team meeting scenarios determined the design of the tasks. The following table describes the tasks and how they were carried out with Mozaic and Acrobat.

Task	Description	Task Example	Steps on Mozaic	Steps on Acrobat
Display Task	Search for any sheet of a specified sheet type and display it on the screen.	Find an architectural Floor Plan and display it	Use Sheet Menu, select appropriate filters to find any Floor Plan and display it.	Find any Floor Plan from the left side linear list and display it
Query Task	Search for a specific sheet and display it on the screen.	Find the sheet named “Floor Plan Level 02” and display it	Use Sheet Menu, select appropriate filters to find the specific sheet and display it.	Find the sheet from the left side linear list and display it
Zoom Task	Use Zoom function to locate information on a given sheet.	Find the detail tag marked as A4-A700 on sheet named ‘Level Ground’	Use Zoom Panel to locate the detail tag.	Use Zoom function from the menu bar and locate the detail tag.
Related-View Task	Find a related sheet that shows a detailed view of an item on a given sheet.	Display the related view for the detail tag B2-A701 shown on sheet “Level Roof”	Drag the stylus across the screen to draw a rectangular box around the detail tag and select a screen from the Screen options pop-up menu	Find the sheet that is referred on the detail tag (in the list of sheets) and then locate the drawing on the sheet. This task involves remembering the sheet naming convention.
Compare Task	Compare 2 or more sheets to answer a question.	Compare between the sheets “Sebastian 3D view”, “Wall 5A” and “Level Ground” and try to locate the exit stairs on the 3D view	Display the sheets on Tiles, locate the stairs on the 2D sheets and finally locate it on the 3D view	Find the 2D sheets, try to remember the location of the stairs, and finally locate it on the 3D view.

Table 4. Task example and task execution procedures

Each task consisted of multiple trials that were similar in nature. Most of the tasks had three trials each, but the comparison task had four trials. For the Zoom task and the Related View tasks the required sheet was already setup by the experimenter with a 1 x 4 Tile layout on Mozaic and a “Single Page Continuous” page display option on Acrobat. During the Zoom Task the subjects used various zoom levels and “within a sheet navigation” feature to navigate around the sheet and locate the detail tag. On Acrobat however, the subjects had to use the Zoom function from the menu bar (View > Zoom) to look for the required detail tag on the given sheet. Table 3 shows a brief comparison of the tasks completed on Mozaic and on Acrobat.

The subjects were allowed to refer to their cheat sheets [Appendix C] while they were using both software, to refer to the definitions, naming and numbering conventions and quick tips to help them during the Related-View task.

The Comparison tasks were lengthier than the earlier set of tasks and required observation, comparative and decision making skills to complete the tasks successfully. An example trial was worded as “Compare between the sheets ‘Sebastian 3D view’, ‘Wall 5A’ and ‘Level Ground’ and try to locate the exit stairs on the 3D view.” Exactly correct answers were not expected from the subjects during this task. However an approximately correct answer was required.

4.2 Procedure:

The user study had two distinct phases: the timed and observed tasks followed by the interview.

4.2.1 Observation of Tasks

Participants used both Mozaic and Acrobat. We designed two sets of similar tasks namely Task Set A and Task Set B [Appendix A]. The order of the Task Sets and the order of the tools were counter-balanced to avoid learning effects. Each participant had to attempt both set of tasks.

The subjects were equally divided into four groups with each group following a certain order of task set and tool used. This is shown in Table 4.

Tool Order → / Task Order ↓	Mozaic followed by Acrobat	Acrobat followed by Mozaic
Task A then Task B	4 subjects (3 males and 1 female).	4 subjects (3 males and 1 female).
Task B then Task A	4 subjects (3 males and 1 female).	4 subjects (3 males and 1 female).

Table 5.Task and tool ordering of participants

The study began by briefing the participant about the background and the nature of the study. This was followed by asking for the participant's consent about being part of the study. Following this, the subjects had to undergo a 45 minute tutorial session which included the basics of architectural sheet drawing and naming conventions, a walk-through of both tools (Mozaic and Acrobat) followed by a short informal interview [Appendix B] to gauge the level of understanding the participant had from the tutorial. The walk-through involved scenarios that emulated the various types of tasks. The subjects could familiarize themselves with the working of the interfaces, and understand the overall layout of the sample 2D and 3D data. The warm-up questions asked during this informal interview were mostly open ended in nature. This was necessary in order for the experimenter to get an overall idea about the user's understanding of the sample data. Understanding of the sample data and basic concepts was key to the study. We did not expect exact answers but close approximations only. If the answer was not satisfactory, the experimenter re-iterated the portion of the tutorial that contained the answer to the question. The subjects were given a "Cheat Sheet" [Appendix C] that they could use when needed during the course of the study. The sheet contained basic definitions of architectural terms, naming conventions and quick tips. It was later seen that this sheet often helped the subjects during the course of the study.

The tutorial was followed by the first half of the study where the subjects had to work with a task set (A or B) on a software tool as shown in the table, followed by the second task set and tool. The subjects were given an option to take a short break of 5 minutes between the two sets of tasks.

Mozaic was introduced with its default layout (i.e. 1 x 4) to the subjects at the start of the study. Acrobat was introduced to the subjects with Page Display set as "Single Page Continuous" and Zoom set as "Fit Page". This was set as the default layout for Acrobat for the study. However the subjects were allowed to set Acrobat with their preferred layout option. It was observed during the course of the study that subjects rarely changed the default display settings on Acrobat. During the course of the study they were also allowed to use the "New Window" function if and when needed. The bookmarks pane of Acrobat listed all the sheets that were present in the file. Sheets were typically named to reflect the type of sheet and the Floor Level they belonged to, for example: Floor Plan Level 02.

Both interfaces had timer widgets attached to them. The subjects were in-charge of the timer during the study. The subjects needed to start the timer before they started a trial and stop the timer after they completed the trial. They started the timer after they had read and understood the given trial. The experimenter observed the subjects working on the trials and verbally guided them during the task if needed. The need for guidance (or a hint) was based on any action performed by the subjects that would lead to a wrong result in the end. To explain, let's look at an example of such a scenario. Example: "Trial: Find the sheet named "Floor Plan Level 02" and display it. Tool: Mozaic. The user needs to select the filters that show "Architecture", "Floor Plan" and "Level02". During this process if the user made any mistake, say selecting "Elevation" instead of "Floor Plan" the experimenter hinted that the user should read the question carefully and check the filter selections." Subjects were aware that the experimenter would provide them with hints if they were doing something wrong during the tasks.

4.2.2 Interview

This part of the study immediately followed the observational part. The subjects were interviewed about the "Ease of use" for both interfaces and their level of understanding of the sample data. The questions that were asked were:

i. How comfortable were you with the overall understanding of the sample architecture?

ii. How often do you come across situations when you have to look at a 2D floor plan or a 3D view? In other words how often do you come across such layouts in public places such as shopping centers and offices? Do you have any past experience working with architectural or construction project data?

iii. Which tasks were difficult to perform on Mozaic as compared to Acrobat?

iv. Which tasks were difficult to perform on Acrobat as compared to Mozaic?

v. What is your overall feedback about Mozaic?

Chapter 5: Results

This section highlights various findings from the usability study and discusses the findings in terms of (1) Observations (2) User Feedback. Timing results are reported in Appendix D.

5.1 Observations

This section puts forward various observations that the experimenter made during the course of the quantitative study. These observations mainly focus on the strategies that subjects took while doing the tasks. We organize these results by the type of tasks – (a) Display and Query Task (b) Zoom Task (c) Related-View Task (d) Comparison Task. We also present some general observations that cannot be grouped under any specific task.

5.1.1 Display and Query Task

With Mozaic, all subjects used the filter to accomplish the task. Most of them only used the options from the Sheet Type set of filters for the Display task. However, some users used the Floor Level filters even when they were not necessary during the display task.

All subjects used the filter effectively for the Query task where they had to find a specific sheet. Some subjects did not use the "Sheet Style" or "Floor Level" filters and depended on alphabetical ordering of the sheets. This resulted in looking through a long list of sheets and views, which made them slow [Appendix D]. We observed that the subjects were familiar with alphabetical ordering of sheets on Acrobat and expected the same on Mozaic. On Mozaic the sheets were ordered by "Sheet Style".

Even though the users selected sheet names from an unfiltered linear list on Acrobat, we think that the interaction was faster on Acrobat because the users did not need to scroll through the list. Scrolling through the list on Mozaic adds an extra level of motor action which is slower that simple visual search. This theory is in accordance with studies that involve Fitts' Law [20, 33].

All subjects selected the sheets from the sheet list on the left hand side of the screen while working with Acrobat. They would either stand at the middle of the table, lean over the table to click on a listed sheet or move over to the left hand side of the table to perform the task. It was interesting to note that the users did not have much time difference between the Display and the Query tasks even though the task type was slightly different. On further analysis, it was noticed that the small list of sheets for the task did not give the subjects many choices for the random selection. In other words, when the Query task required choosing a specific sheet, it often turned out that the subject had already chosen the sheet before from the preceding Display task.

5.1.2 Zoom Task

Zoom task required users to look for certain items on a sheet. Some users took considerable amounts of time while doing this task on Mozaic. This was primarily because of two reasons - (a) the strategy used to parse the sheet (b) not effectively using the various zoom levels or (c) combination of both. This often led them to comment about the resolution of the screen, shaky image, and the need for a bigger Zoom window and a gradual zoom level. During this task most subjects did not seem to have any issues with the design of Zoom function on Mozaic, With Acrobat, all users leaned over the table, or moved to the left side of the table to work with the zoom function from the menu bar (under View). Leaning over the table was often disruptive because parts of their clothing hung close to the surface of the table making the table un-reactive to multiple inputs (as it can only accept one input at a time). It is important to note that the subjects were warned of this table behavior before they started the study.

However there was one user who used the Pan and Zoom window (Tools > Select and Zoom > Pan & Zoom Window) during this part of the study. The user effectively used this Acrobat feature to complete the task.

5.1.3 Related-View Task

All users were able to complete this task with Mozaic. On the contrary, when the subjects worked with Acrobat, they were visibly very frustrated. The subjects had to switch back and forth between the sheets to complete their task. This often involved remembering the location on the reference sheets and recalling the specified sheet number. We observed that most of the subjects had to often refer to the Sheet numbering reference. This behavior often led to complaining about the method used to find the relevant information the specified sheet. The subjects complained about not having an "easy" way to find the related diagram on the referred sheet. It was observed that the subjects stood on the left hand side of the table to find and select the sheet they wanted, and then walked to the right hand side of the table to check the sheet number. This was primarily because the sheets were so large that they covered the whole screen, and the list was fixed on the left side of the screen.

5.1.4 Comparison Task

With Mozaic, most subjects used multiple tiles to set up the sheets they needed to work with. They often used an unused Tile for temporary bookmarking. This means that they used one Tile to store a particular sheet for future use once they knew which sheets they would need. Most users used the 1 x 4 or 1 x 2 display format depending on the number of sheets they needed to use to complete the task. Most users used the zoom function efficiently to complete their tasks.

However, in this process they did spend a considerable amount of time in searching for items on the sheet.

However, two users who had prior experience working with architectural data and mechanical engineering data took a slightly different strategy while doing this task. They took advantage of the big 1 x 1 display while foraging for specified items on the sheets. In other words, they used multiple sheet views for comparison tasks, but switched back and forth between 1 x 1 and 1 x 4 display formats to get a better view of the items on the sheet. They used the zoom function less than rest of the subjects. This strategy resulted in a better performance time with the tool during the comparison task. Average time taken by these users (85 seconds) was 22 seconds faster than that of the average time taken by all the users (107 seconds) to complete this task on Mozaic. This was an important observation but it is statistically insignificant because only two subjects used this strategy. It is also important to report that there was a participant in the study whose performance with Mozaic was far better than the rest of the other 15 subjects. It is further interesting that this participant uses tabletops extensively. The subject's feedback during the interviews hinted that she found Mozaic easier to use because the software catered to a tabletop environment as opposed to Acrobat. The subject also mentioned that she did not perceive Acrobat as software designed for tabletops and therefore it was frustrating for the subject to work with it.

In comparison, the subjects switched back and forth between the given sheets while working with Acrobat. The subjects often depended on memory recall for this set of tasks. A few subjects made multiple copies of the Acrobat window (using New Window from the Window option in the Menu bar). This resulted in displaying a separate window on top of the original Acrobat window. The subjects then opened up multiple sheets on these multiple windows, rarely adjusting the size of these windows, and switched back and forth between them during the course of their work. One participant asked the experimenter whether she could make multiple copies of the original file and display each copy on the screen.

It was observed (reported later) that the subjects were comfortable while working with the 1 x 1 default display on Acrobat, although they complained about needing to switch back and forth to refer to multiple sheets during this task.

5.2 General Observations

We observed that some users tried to drag the sheets directly onto the screen instead of dropping them onto the Sheet Quadrants while they were trying to display the sheets on the screen. This suggests that such a feature should be included in later versions of Mozaic. Subjects reported that they did not like having to move around the table while working on Acrobat.

5.3 Results of Interview

The qualitative interviews reflected on – (a) the software's ease of use and (b) subjects' level of comfort with the architectural data.

5.3.1 Ease of Use

Fifteen out of sixteen subjects felt that Mozaic was quite intuitive and easy to use (based on feedback) in general. One of them reported that they did not like the double tap method of displaying the Menu system, and that it made the work flow slow as compared to Adobe, which already has the sheets displayed on the left hand side of the screen. The same user however said that the menu system was "cool". Most users favoured the idea of having a setup to display multiple sheets at one time and that the display resolutions could be changed when needed. One user commented that the strength of Mozaic was the multiple displays. In the user's words, the most useful feature was the "…Multi-screen display and that you can control each one individually and separately from each other…".

The users favoured the way reference sheets are displayed through the Related- View interaction in Mozaic. A user who had prior experience with architectural data commented, "..it is way simpler and faster…" while explaining how he felt while using the Linked View function.

Being asked about the zoom function, most users seemed to understand the motive that encompasses the design of the zoom function, however they suggested reducing the screen jitter when a user's stylus is fixed at a location on the zoom window. This was a result of the tabletop cameras constantly triangulating the position of the stylus on the screen. One of them commented that it felt difficult to run any task that involved the use of the zoom function, primarily because of the screen jitter. The user also suggested that adding a few more (gradual) zoom levels might be helpful. Most users suggested a slight modification to the zoom function by reducing the jitter on the screen. One user however, suggested designing the zoom window slightly bigger in size. Most users seemed to like Acrobat in this respect even though they had to often move around or lean over the table to activate and adjust the various zoom options.

While being probed about more critical comments around the tasks and the software design, it was evident that the users liked the idea of the filter based menu system of Mozaic. A few users commented that this style of filter-based design was an easier means to search for sheets when there were a larger number of sheets involved. However, they felt that Acrobat met their needs in the study because the total number of sheets involved in the study was small. Four users suggested ordering the sheets in the Listbox alphabetically, rather than by Sheet Style. A few suggested adding filters to the Sheet Menu based on alphabetical ordering.

Most users liked the idea of a single large display while working with Acrobat, even though they needed multiple displays when working with multiple sheets. All users unanimously agreed that searching for a sheet was easier with Acrobat as most of them said something like, "..it was already there on the left hand side of the screen".

5.3.2 Level of Comfort:

Most users reported that they felt comfortable and had some basic understanding of the data while running the task. Initially they felt a bit challenged by all the architectural information that they had to work with, but gradually within the course of the study they felt "at ease". It is important to note here that the users were asked about whether they were comfortable with the sample architectural data after they completed the tutorial at the beginning of the study. The study was conducted only after the users felt that they understood what they were expected to do with the data and that they felt comfortable to take part in it. A few users reported that the "Cheat Sheet" provided to them helped them through the task, especially with the Related-View task on Acrobat. On being asked about how often the subjects come across such data, most of the users' comments ranged from rarely to sometimes. Two users reported of extensively using such data in the past.

Chapter 6: Discussion

The exploratory study allowed us to observe various advantages and disadvantages that the current iteration of Mozaic has to offer. We discuss these in terms of the task types and the effectiveness of the central design ideas – filter based query, circular pop-up menu based tool collection and tile based display.

Mozaic was designed to investigate the effectiveness of various proposed design guidelines at design meetings. We wanted to investigate whether a simple collaborative interface can improve accessibility of information. Our definition of accessibility of information includes searching for a required sheet, displaying it and finding relevant information on it. The interface was designed with collaborative aspects in mind but assuming it would be mainly used by a driver during design team meetings. The user reviews bolster the strengths of the design like access to multiple displays and location independent system access. Tile based display, circular menu based access to the system tools and simple interactive techniques backed up by user feedback suggest that the initial design of Mozaic is a positive direction of interface design for team meeting situations, However, the effectiveness of this design can only be tested by using it in real world situations..

6.1 Discussion of Tasks:

Let's take an in-depth look at the tasks and try to analyze how various alternate designs on Mozaic and Acrobat influence different user strategies while working with the tools.

6.1.1 Display and Query Task:

Linear list of sheets on the left side of Acrobat (which requires mainly visual search) certainly makes search on Acrobat faster [Appendix D] as compared to filter based querying of sheets (which depends on a slower motor task) on Mozaic. This phenomenon is supported by previous studies on Fitts' Law, and visual search on a list [20, 33]. But the question that still needs to be asked is whether this linear list would continue to be faster when there are significantly more sheets on the list. The filter based query system is designed to be used for effective querying and gives the user numerous search options. A user does not need to remember the name of a sheet in order to find it, as long as he remembers the Sheet Type, Sheet Style and Floor Level of the sheet. Searching for a sheet on Acrobat entirely depends on the name of a sheet or other attributes like position of the sheet on the linear list. These two strikingly different designs provide different ways to access the document collection, which may come in handy depending on the kind of task and the type of information a team member seeks to find.

The list based (always visible) design approach is beneficial to desktop systems where users perform virtual navigation tasks on a screen that is small in size. Application of such design feature on a tabletop interface (that is significantly different in terms of display area and orientation) would mean that a person has to physically move around the table or the driver needs to be located near the list. On the contrary, having a menu system that can be accessed by any team member allows every team member access to the data. This design concept goes hand in hand with some guidelines proposed by Fard.et al. [12] and Scott et al. [45].

Analysis of the Query task showed us that most of the subjects searched for items in alphabetical order. Acrobat follows this ordering, but Mozaic did not. Moziac ordered the sheets by the "Sheet Style" property instead. This brings us to the question, what is a better way to order documents on a list? Alphabetical ordering certainly makes information access faster when one has knows the name of the sheet one is looking for. If this is not the case, one can search for sheets in terms of the type or style of a sheet. Designs that allow such querying for documents can be beneficial for design team meetings but features like linear lists that allow rapid access to information should be considered as well.

6.1.2 Zoom Task:

While working with Acrobat, the subjects had to move around or lean over the table often to adjust the zoom function. This was often very time consuming and as reported by the subjects very frustrating. But the good side to this zoom interaction was that it did not involve any jitter particularly because there was no “within the sheet” navigation involved. In other words the whole sheet was displayed at all times. Therefore if a subject needed to parse through the information in the sheet, he needed to either use the scroll bars or use the “Hand” tool on Acrobat.

In the case of Mozaic, the Zoom function was designed to engage more collaboration among teams working together. By this, we mean that this function was designed not only to manipulate a sheet but also to support conversations among small teams (as described in Section 3.9) without interfering into other’s conversations. This collaborative element of design in this function allows teams to hold conversations between members who are not located close to each other. This aspect allows team members to converse without interfering with group activities.

The left-side location of the zoom function on Acrobat (along with the sheet list) dictates the driver’s location around the table. However, a pop-up menu based access to the zoom function on Mozaic allows any member around the table to access the function and use it.

With Mozaic, the zoom function can be used on any displayed tile at any time. This minimises interference with group activities and allows small groups to hold side conversations. In contrast, Acrobat does not have such a feature and therefore it perhaps does not engage smaller groups of people to have conversations without interfering with others’ activities. However, the similarity of the Zoom tool (Tools > Select and Zoom > Pan and Zoom Window) on Acrobat with that of Mozaic suggests that people find it useful to have an overview of the magnified display.

Such overviews allow the user to remain focussed on the displayed information and easily navigate through the magnified information at hand.

6.1.3 Related-View Task:

The Related-View feature on Mozaic allowed the users to switch back and forth between related diagrams. This was faster on Mozaic as compared to Acrobat [Appendix D]. This "selection" gesture was intuitive and the tile based display allowed users to display relevant related information on any tile of their choice. We think that the pop-up based Screen Options along with tile based design concept allows users to display information without having to lose information that is being displayed. It gives the users enough choices to display related data, thus improving accessibility to displayed and related information. We think that this feature can be helpful especially when 2D elements of a drawing are connected to their corresponding 3D elements in future.

Acrobat did not have such features, and therefore the users were visibly frustrated while doing this task. This makes us believe that interfaces designed for meetings should include interaction techniques that allow smooth transition between related documents.

6.1.4 Compare Task:

The Compare tasks shed light on the advantages and disadvantages that Mozaic has to offer and highlighted the features of Acrobat that can be incorporated into future versions of collaborative software designed to cater team meetings. We observed various strategies that users undertook while completing this task. Most of the users used the 1 x 4 display mode and used the zoom function extensively. Their task performance was affected by – (1) Screen jitter and (2)

Searching techniques. Most users followed a random path on the sheet to look for items in the sheet and often passed over the same items over and over again. By contrast, two users searched for items based on their assumption about the items' location. However, it is not clear how they made the assumption. For example, if the task involved "counting the number of stairs depicted on the floor plan", they spent most of their time looking for stairs around the inner and outer boundary of the floor plan. We think this strategy helped them to work faster than the rest of the users. This brings us to ask ourselves, is this strategy learned with experience or just individual variation? We do not have any specific answer to it but from what we observe, this is an effective strategy. This strategy has more impact on Mozaic primarily because the user can effectively and quickly navigate through the sheet using the zoom function while comparing with another sheet displayed beside it. It was also noticed that these two users took advantage of the display modes (1 x 1, 1 x 2, 1 x 4) more extensively than the other users. In other words they took advantage of the 1 x 1 display more than the rest, thereby reducing their individual time in task performance. These users found a way to temporarily bookmark sheets using the display modes, an action which they were not able to do in Acrobat. In Acrobat, the user has to switch back and forth between the sheets. We believe that 1 x 1 display encourages physical navigation [2] within a document, and makes it easier for an user to come to a decision. All the users used a large view of the sheets while working with Acrobat which helped them in finding items on the sheet or coming to a decision faster most of the time. We did not observe switching between display modes on Acrobat.

The tile based display concept allowed the users to display multiple sheets side by side. The users commented on this multi-display feature of Mozaic as "useful" and "nice". This helps with access to data, reducing repetition and involves more physical navigation [2]. In contrast, the singular or overlappable (when using New Window feature) display of Acrobat made the users switch back and forth between the displayed sheets, and the fixed position of the sheet list made the users move around the table (particularly during the process of displaying a sheet). This feature of Acrobat clearly hinders information access especially when we try to think of this task being carried out during meetings where there would be multiple people around the table.

This suggests that future designs should incorporate features that allow a tile based setup, but there should be a way to quickly switch to a large 1 x 1 display.

6.2 Recommendations:

Collaboration is an important aspect of design meetings and it has been emphasized in past research [45, 52, 12]. We expect that Mozaic's design features should better support collaborative meeting activities such as subgroup discussions. But speed of access to information makes us believe that certain design aspects of software like Acrobat can be incorporated into interfaces that are designed to be used on tabletops during design team meetings. In future systems designed to provide access to design information during meetings we recommend:

- A Tile based layout to display, share and compare documents side-by-side.
- A quick way to switch to a display feature that allows large display of a single design sheet.
- A pop-up menu based control to allow universal access to the system.
- A non-filtered linear list with an option to apply filters if needed.
- Simple interaction techniques that require low dependence on motor tasks yet mimic familiar technology.
- Within sheet navigational functionality that provides the user with a miniature overview of the sheet.
- Functionality to quickly navigate between related (or referenced) drawings and 3D views.

What needs to be measured in future is the effectiveness of such features in facilitating information access during team meetings.

6.3 Threats to Validity

We conducted a usability study to evaluate Mozaic. The usability study mainly focussed on the functional aspect of the interface design. The usability study tried to help us understand the effectiveness of Mozaic's design and how our four major design ideas fit in with the current practices in the construction industry. The participants of the study were mostly students, the majority of whom did not have experience with the construction industry. This factor may have affected the generalizability of our study.

However, since the study was intended to understand the usability of Mozaic's design, we think that the participants presented us with a good understanding of interface problems that we suspect would also be encountered by the professionals. In other words, the participants' actions presented us with a foundation to predict what professionals may need in future iterations of the software.

Furthermore, two participants from the usability study (who had some experience with the working of construction industry) expressed their satisfaction about the software prototype. Both of them commented on how searching for the right sheet during meetings can be frustrating and that Mozaic tries to address this issue from a Filter based query perspective. They reiterated that both Linear list and Filter query is necessary during meetings. According to them the strength of the software lies in its ability query for specific sheets and display related diagrams on related sheets. They further expressed that they would like to see such features into commercially available software.

To conclude this section, we believe that even though the study is not quite generalizable in terms of its use, it provides us with observational clues about the "useful" and "not quite useful” features of Mozaic. It also highlights the usefulness and drawbacks of using Acrobat during construction meetings.

Chapter 7: Conclusion and Future Work

Our initial goal was to investigate the feasibility of using tabletop displays for design team meetings. Earlier research suggested that tabletop displays could provide immense benefits to such meetings by engaging team members. This could potentially be achieved by designing an interface to cater to the needs to design team meetings. We applied already existing generic design guidelines for tabletops to the preliminary design of an interface and observed how users interacted with it. We compared user interaction and strategies while users worked on a tabletop display with an interface that is designed for desktop environments. The observations from our exploratory study show us that the preliminary design ideas like Tiled display, circular pop-up menu of Mozaic are promising. The tile based display allows the user to effectively display, navigate and compare between sheets. The pop-up menu allows users to access various navigational tools from anywhere around the table. We believe that this feature will encourage team members besides the driver to interact with the system when needed. Functions like the Related view function allows users to quickly switch between related views and drawings. Unlock and Zoom functions allow navigation within a sheet even when a sheet is passed around the table. The effectiveness of these design ideas depend on the user strategy and the task. Users who prefer virtual navigation may have different results from those who prefer physical navigation. Users who use the pop-up menu less (than users who use it often) and prefer to display the tools on the tabletop during the course of the task may find that information access is quicker.

However, features like linear list and a large display area are effective and allow users to search for information quickly [Appendix D]. This is an important design feature that needs to be considered while designing interface for building design meetings.

These design considerations need to be explored further and tested in real world situations with design team members who rely on collaboration.

Even though this work focuses on the practices of the construction and architectural industry, the design ideas could potentially be used in other engineering areas where design team meetings are central to the industry.

7.1 Future Work

Possible design changes in the future iterations of Mozaic are as follows :

- Alphabetical ordering in the Sheet Menu filter.
- Increasing the size of the Zoom Window.
- Gradual Zoom levels
- A fixed linear list of sheets, preferably as side panels.
- Remove jitter on screen by using some averaging function to stabilize the location of the stylus on the screen while using Zoom display.
- Individual size and arrangement controls for the Tiles, like options at the corners of a Tile.
- A non-filtered linear list with filters that allows the user to use the filters if needed.
- Focus on adding features to Mozaic to allow more collaboration among team members.

We can also incorporate features to attain smooth translation and rotation of sheets on tabletop displays along with features to display the text in correct orientation for the users depending on their handedness and location around the table [18]. With this addition the interface will be able to guess an approximate location of the user holding a pen over the interface, resulting in orienting a sheet or text towards the users direction allowing the user to read and understand better.

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Appendix A:

List of Tasks:

Instructions:

- Each task comprises of trials. You **need to complete** each and every task and trial.
- Please **follow the order** of each task and trial.
- You will need to START the timer before each trial and STOP the timer after you are done with the trial.
- Please read-out the tasks and trials BEFORE you start the timer. Feel free to ask any questions to the experimenter before you start the task or trial.
- Please **wait** for the experimenter's instructions to START and STOP the timer.
- Each task in independent, however the trials may be similar.
- Please refer to the "Cheat Sheet" as on when required during the course of the study.
- Please remember that the experimenter will provide you with assistance if necessary.

Set A:

Display Task (Please Display the sheet on the screen after finding it):

- Find an Architectural Floor Plan and display it.
- Find an Architectural Reflected Ceiling and display it.
- Find an Architectural Vertical Circulation (Stairs) and display it.

Query For specific Sheets (Please Display the sheet on the screen after finding it):

- Find the 3D view named "Sebastian 3D view" and display it.
- Find the sheet named "Washrooms Level Ground" and display it.

- Find the view of the building called “View from Southeast”.

Zoom (Please wait for instructions before you start this section) :

- Find the detail tag marked as A4-A700 on sheet “Level Ground”.
- Find the detail tag marked as A3-C04 on sheet “Level 04”.
- Find the detail tag marked as A4-C06 on sheet “Reflected Ceiling Level Roof”.

Linked Views (Please wait for instructions before you start this section) :

- Display the related view for the detail tag A4-C06 shown on sheet “Building Section E-W”.
- Display the related view for the detail tag A1-A351 (**marked with a red dot**) shown on sheet “Reflected Ceiling Level 03”.
- Display the related view for the detail tag A4-A700 shown on the sheet “Level Ground”.

(**5 minute break if needed**)

Comparison Task (Please wait for instructions before you start this section):

- Open sheets “Level Ground” and “Arch Abbreviations”. Count the number of “Continuous Wood Framings” on the Ground Floor Plan (A4).
- What type of material is used to construct the “acoustic material” on sheet “Wall 7” (A1 Auditorium Wall Plan detail)?
- Compare between the sheets “Sebastian 3D view”, “Wall 5A”and “Level Ground”; try to locate the exit stairs on the 3D view.
- Open the sheets “Building Section N-S” and “Level 02”. Point out the approximate location of “Building simulation / software lab” on the “Sebastian 3D view”.

Set B:

Display Task (Please Display the sheet on the screen after finding it):

- Find an Architectural Floor Plan and display it.
- Find an Architectural Reflected Ceiling and display it.
- Find an Architectural Vertical Circulation (Stairs) and display it.

Query For specific Sheets (Please Display the sheet on the screen after finding it):

- Find the 3D view named “Sebastian 3D view” display it.
- Find the sheet named “Washrooms Level Ground” and display it.
- Find the view of the building called “View from Northwest”.

Zoom (Please wait for instructions before you start this section) :

- Find the detail tag marked as A4-A701 on sheet “Level Ground”.
- Find the detail tag marked as A3-C01 on sheet “Level 04”.
- Find the detail tag marked as B2-A700 on sheet “Level Roof”.

Linked Views (Please wait for instructions before you start this section) :

- Display the related view for the detail tag B2-A701 shown on sheet “Level Roof”.
- Display the related view for the detail tag A4-A701 (**marked with a red dot**) shown on sheet “Stair 2”.
- Display the related view for the detail tag A1-A701 shown on the sheet “Level Ground”.

(**5 minute break if needed**)

Comparison Task (Please wait for instructions before you start this section):

- Open sheets “Reflected Ceiling Level 03” and “Arch Abbreviations”. Count the number of “Ceiling Light Fixtures” on the sheet “Reflected Ceiling Level 03”.

- What type of material is used to construct the “Glulam Beam” on sheet “Wall 6” (image A4)?
- Compare between the sheets “Sebastian 3D view”, “Building Section South Bar N-S” and try to locate the “Data & Modeling Lab” on the 3D view.
- Open the sheets “Building Section N-S”, “Copy of Sebastien 3D view” and “Level 03”. Point out the approximate location of “Office/ Lab Bar” on the 3D view.

Appendix B:

List of Warm-up questions:

- Please explain where this floor (level 02) plan is relative to this 3D model?
- Which direction are you facing the building from on this N-S elevation?
- How will you display the sheet “Floor Plan Level B1”?
- How do you know what type of material is used to make a particular wall? (Hint: cross reference with the sheet that depicts the legend and abbreviations).
- Show me the location of the CIRS office and the Solar Aquatic Bio- filter room in the building?
- Discuss the steps verbally
    - Showing a related diagram on Mozaic.
    - Showing a related diagram on Acrobat.

** Note: These questions were verbally asked after the subjects went through the tutorial and the practice session.

Appendix C:

Cheat Sheet:

Every architectural sheet is numbered according to a universal convention.

Here is a sample sheet to show the numbering convention and what the numbers mean.

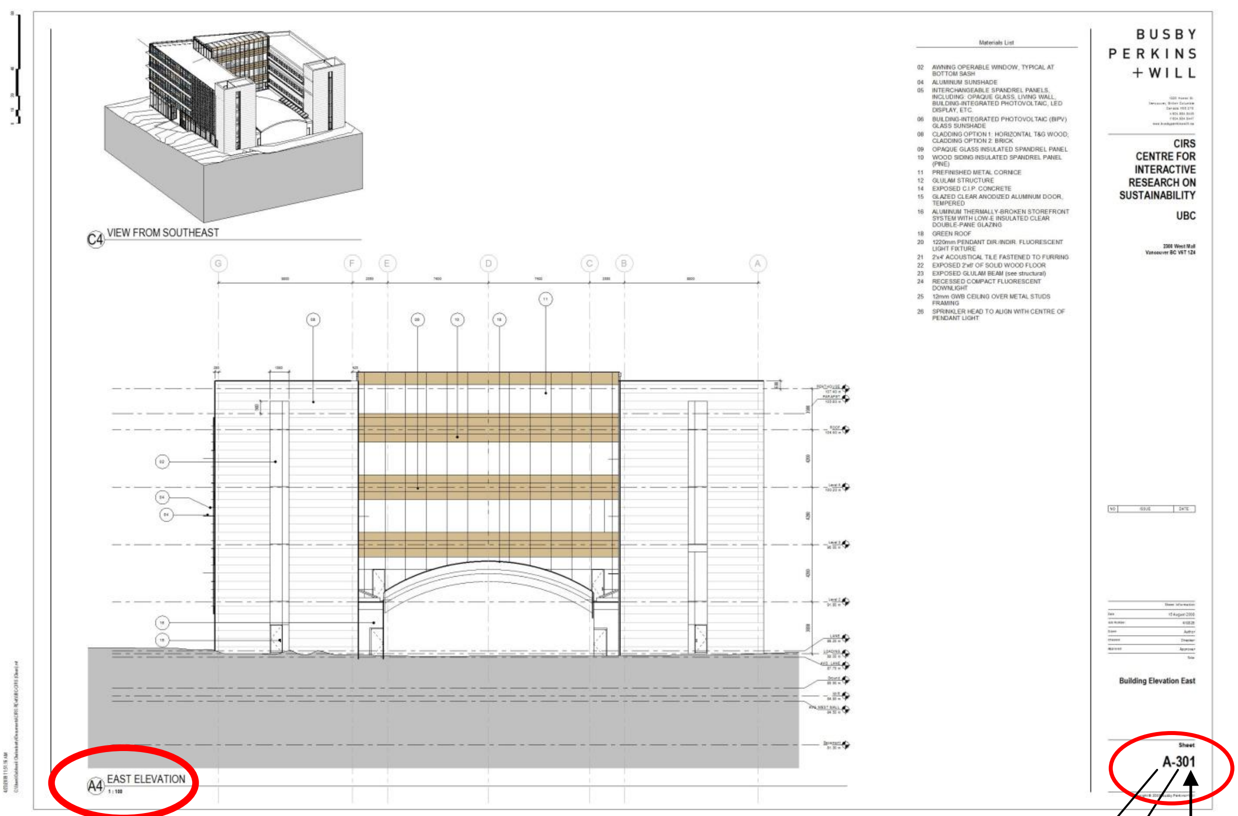

Figure 13. Architectural Sheet

Architecture.

Diagram number on the sheet.
**Note: There can be multiple diagrams on a sheet, each diagram is depicted by a diagram name and number.

The Number "3" represents that the sheet depicts the "Elevation" of the building. Refer to the table below.

The unit's place signifies the Floor Number. In this case it is the 1st floor. The ten's place signifies the Category Number. In this case "0" refers to the "Building Elevation".

A general example of the numbering convention:

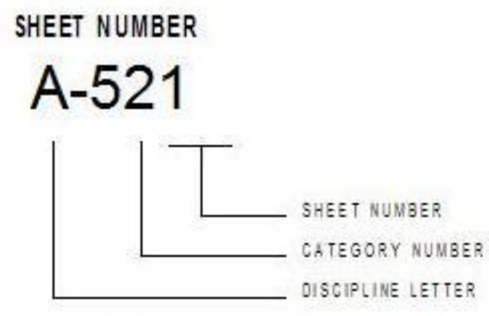

Figure 14 Sheet numbering scheme

Quick Reference:

To find the type of sheet you are asked to find, look for the hundredth's placeholder of the Sheet number and refer to the following table:

If the hundredth's placeholder is :	**Representations :**
1	Floor Plan
2	Reflected Ceiling
3	Building Section(Category # 1) or Building Elevation(Category # 0).
4	Wall Section or simply Section
5	Washrooms
C 01 /C02 ****	Walls
7	Vertical Circulation (Stairs)

Table 6. Quick reference table

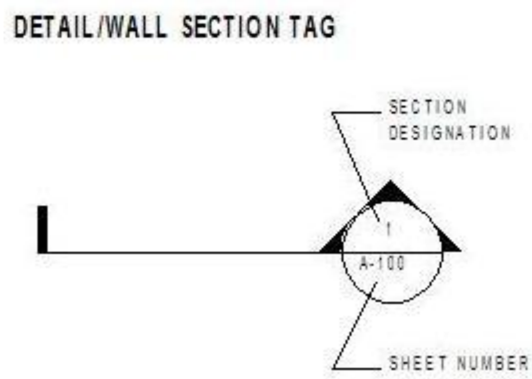

Figure 15. Detail Tag

Definitions*:

Floor Plan : A floor plan in building engineering is a diagram, usually to scale, showing the relationships between rooms, spaces and other physical features at one level of a structure.

It is a projection of a 3D building from the position of a horizontal plane through the building such that the portion of the building above the plane is omitted to reveal what lies beneath.

Section: A building section shows a view along an imaginary line cut through the building, indicating structural and construction elements.

Reflected Ceiling: A reflected ceiling is drawn as if the image of the ceiling was reflected onto a mirror on the floor. It is not a view of the ceiling looking up at it. An alternative approach is to imagine the ceiling is transparent. The view is looking down from above through the ceiling to the floor below.

Elevation: An elevation is a drawing of one side of a building - the front, the rear and the sides.

Vertical Circulation / Stairs: Provides a schematic view of the structures that allow people to access and travel between the floors.

[* These definitions have been cited from www.Wikipedia.org and http://architecturexpression3.wikispaces.com]

Appendix D:

Time Calculations

Results were statistically analyzed using repeated measures analysis of variance (ANOVA) followed by Bonferroni-corrected pairwise comparisons. We performed Q-Q plots to check the data distribution which suggested that we should use a natural logarithm of time data. This was necessary to improve the fit to a normal curve. When Mauchly's Test of Sphericity indicated it was necessary, we used Huynh-Feldt correction. Factors in analysis were the Interface (2 levels) and Task Type (6 levels). Fig.16 (page 78) shows the distribution of the mean time taken to complete the task for the tools used. Error bars represent 95% confidence intervals.

Tests of Within-Subjects Effects

Source		Statistics			
		df	F	Sig.	Partial Eta Squared
Interface	Sphericity Assumed	1,15	.102	.754	.007
Task Type	Huynh-Feldt	4,60	372.838	.000	.961
Interface * Task Type	Huynh-Feldt	3.58,53.70	92.132	.000	.860

Calculated using alpha = .05

Table 7. Tests of within subject effects (with corrections)

We noticed (Table 6) that interface did not significantly affect the task time ($F(1,15)=0.102$, $\eta_p^2=0.007$, $p= 0.754$), and that Task Type significantly influenced the response time ($(4,60)=372.84$, $\eta_p^2=0.96$, $p= 0.0$). We also observed that Interface x Task Type had a significant influence on response time ($F(4,60)=92.13$, $\eta_p^2=0.86$, $p= 0.0$). This means that the time taken to complete the tasks was strongly influenced by the type of task and there was no evidence of a significant overall effect of interface. Interface did have a significant effect within given task types.

Pairwise Comparisons

Measure:Ln_of_Time

Task_Type	(I) Interface	(J) Interface	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
Display	Mozaic	Acrobat	.405	.096	.001	.202	.609
Query			0.911*	.093	.000	.711	1.110
Zoom			0.171476	0.127696	0.199289	-0.1007	0.443653
Linked			-1.896*	.149	.000	-2.214	-1.578
Compare			0.334*	.077	.001	.169	.499

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Legend:

Acrobat Faster

Mozaic Faster

No Significant Difference

Table 7.

Table 8. Pairwise Comparisons of the Interfaces for each Task Type

Pairwise comparisons (Table 7) showed that for Display, Compare and Query tasks, subjects performed significantly better with the Acrobat interface. However, the performance with the Linked View tasks was significantly better with the Mozaic interface. Differences between Acrobat and Mozaic were not significantly different from each other for the Zoom task.

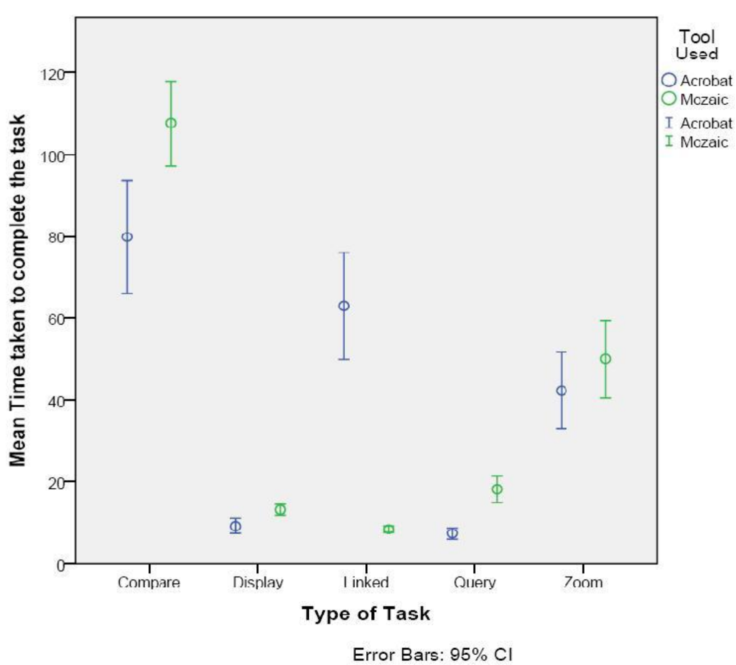

Figure 16. Mean Time vs. Type of Task

Appendix E:

Design Decisions

The current design considerations for Mozaic went through several iterations. The design considerations were made after careful observations were made through reading ethnographic documentation and watching video recordings of two meetings. In the following paragraphs we describe the design decisions (sketches) in terms of the stages of design. We highlight the four main design ideas.

Phase 1:

We focussed on gathering various design ideas during the initial stages of design. We spent time during this phase in observing video recordings (collected from ethnographic study) of various design team meetings. These observations helped us to understand the needs and requirements for the design of an interface that would cater to information access during meetings. We were interested in observing various issues that led to bottlenecks caused by lack of access to information during meeting situations. These observations helped us in designing a rough sketch [Figure 17] of the desired prototype.

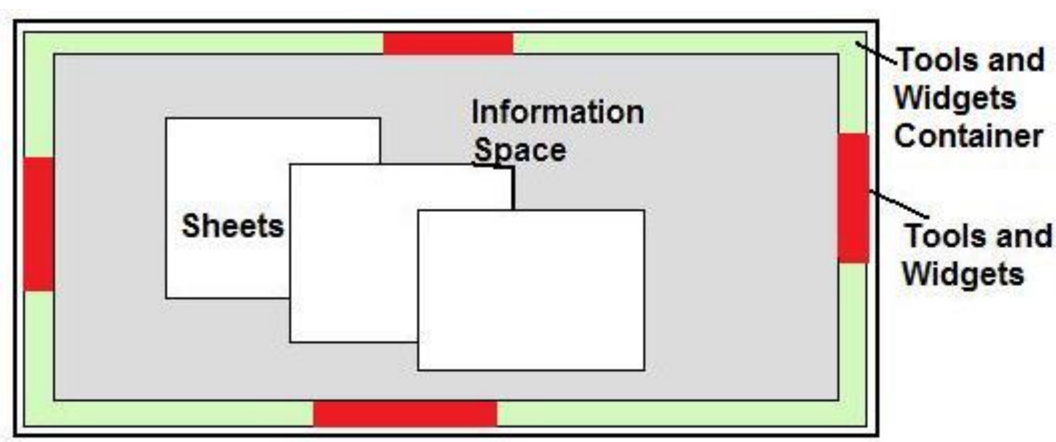

Figure 17: Rough Sketch of Prototype

Tiled Display:

The two major ideas behind the design of the interface were (i) Display of Information (ii) Access to information. Both display and accessibility of information from different parts of the table often hindered the flow of conversation during design team meetings. We planned our interface around the idea of visibility of information. We also decided to design the prototype such that it mimics the ambience provided by a table during regular paper based meetings. Therefore we decided to have a large Information Space [Figure 17] in our design where the sheets and the plans will be displayed. The sheets will be displayed in respective “Sheet Containers”. Based on our observation from the videos we decided to have a maximum of four containers at any instance of the meeting. We decided to provide a resolution of 1200 x 800 pixels (default) for the sheets especially since previous ethnographic work suggest that design team members often tend to work with smaller (A4) sized representations of a drawing sheet. However, we realised that the users may need to change the size of the sheet displayed in front of them, therefore we wanted to make provisions for smooth translation between the uses of different sheet resolutions. Since we aimed at displaying sheets that could be moved and passed around (like physical paper), our initial design consideration was to display the sheets as a virtual stack. We envisioned our design of the Information Space with one “Primary Sheet” supported by three “Secondary Sheets” in the default layout. We define the Primary Sheet as the sheet which contains the diagram that is being discussed about at any particular moment of team discussion. Secondary Sheets are the sheets that contain supporting information to aid the process of discussion.

Menu for Universal Access:

Since accessibility of information was another priority, we decided to place Tools and Widgets [Figure 18] for interaction with the information space around the borders of the table.

This menu could be accessed from all corners of the table according to this initial design. On our initial design, we decided to replicate multiple instances of these Tools and Widgets around the table which within a Tools and Widgets Container [Figure 17]. This container allowed the tools to be passed around the table to different team members when needed. Based on the observed ethnographic videos, we focused on manipulation tasks like zoon-in and out of a sheet, changing resolution of a displayed sheet and querying for a sheet using the Filter (discussed later). The Universal Access Menu comprised of all the tools and widgets and the container that allowed the above mentioned actions to be performed.

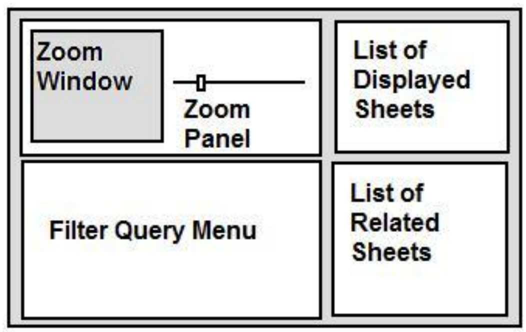

Figure 18: Tools and Widgets

As shown on Figure 18 the Tools and widgets comprised of the Zoom Panel, Filter Query Menu, a List box for Displayed sheets (on the screen) and a list of Related Sheets (discussed in the Linked View section). The Displayed Sheets list aimed to provide the user with the names of sheet that were currently displayed on the screen. This was different from the List box inside the Filter Query Menu [Figure] which aimed to display the list of queried sheets.

Filter:

We focused on designing a Query based filter and therefore our initial design is represented by Figure 19. This initial sketch of the filter depicts a matrix based design for the Sheet Type, Sheet Style and Floor Level. Selecting the squares on the matrices queried for the sheets which were displayed on the list box. The Filter also contained checkboxes to change the resolution of the display. Querying for sheets meant selecting the boxes from the Sheet Type, Sheet Style and the Level matrix layouts. Consequently the queried sheets would be displayed in the Displayed Sheets List box as shown on Figure 19. In order to display a sheet, the user needed to drag the displayed sheet from the Sheet List box to a Sheet Container. This task can also be achieved by dragging a sheet from the Sheet List box to the Displayed Sheet List box.

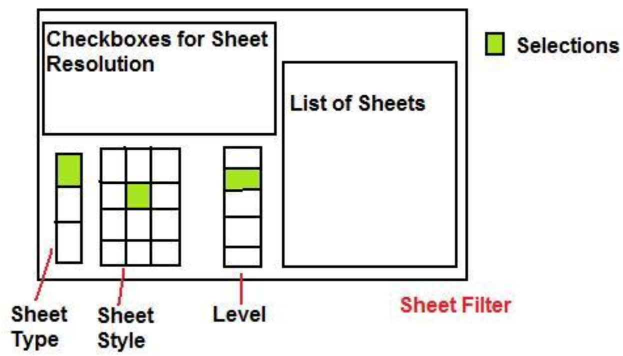

Figure 19: Sheet Filter

We realised that users may need to change the resolution of the displayed sheets, therefore we provided options in terms of checkboxes. These checkboxes would represent pre-determined sheet resolution for all 4 displayed sheets.

Linked View:

We initially decided to list all the related sheets of a particular selected sheet in the Related Sheets List box as shown in Figure 18. In other words when a displayed sheet (on the screen) was selected the Related Sheets List box updated the names of the Sheets associated to the displayed sheet. In order to display the "Linked Sheet" the user had to drag and drop the name of the sheet from the List box to any Sheet Container.

Phase 2:

At this stage we stressed on improving the ideas of information display and querying.

Tiled Display:

We soon realised that the displayed information (sheets) is often used for comparison tasks. We decided to make Sheet 1 (shown in Figure 20) as the “Primary Sheet” and the rest as “Secondary Sheets”. Since side-by-side arrangement of sheets aids the process of comparison we decided to design the workspace shown in Figure 20.

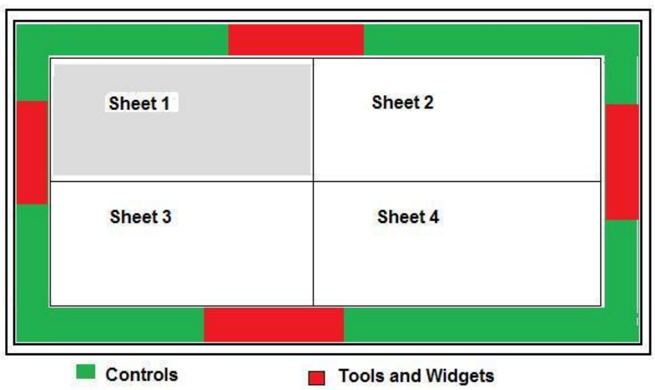

Figure 20: Side-by-side arrangement of sheets

We introduced the idea of 1x4, 1x2 and 1x1 display at this stage. This allowed the prototype to display the information in varied resolutions and pre-defined display setups.

Menu for Universal Access:

Filter:

At this stage of design, we emphasized on the database setup for smooth querying of the sheets. Even though the matrix based design idea for query selection was sleek in design, we discontinued it during this phase. We realised that the design did not encourage proper readability of various “Sheet Style” categories. We decided to use checkboxes and proper spacing to allow clear readability. The current instance of the prototype [Figure 7] depicts this design consideration.

Linked View:

During this phase of design we decided to link the "Detail Tags" on the sheets with corresponding related sheets. This meant that selecting a Detail Tag on a displayed sheet would highlight the corresponding sheet name on the Related Sheets list box, thereby allowing the user to visually relate a Detail tag to its corresponding sheet name.

Phase 3:

This was the final iteration of the software before conducting the Pilot studies. We focussed on making the prototype more intuitive and therefore we observed the ethnographic videos one more time in order to make sure we did not miss any critical details. Not many significant observations were made in this phase of observations but we realised that the current iteration of the prototype was lacking in some respects. This is described below in terms of our four main design ideas in the following sections.

Tiled Display:

No changes were made to this design feature during this phase.

Menu for Universal Access:

Since we wanted to make the interface design independent of the driver's position we decide decided to give it a more universal feel. Since we had envisioned that the driver would interact with the interface more than other team members, we focussed more on the actions of the driver. It is also important to reiterate that the interface is meant to be used by other team members as well (besides the driver) but their need to use the interface is less as compared to that of the driver. Also, from an aesthetic stand point we wanted to give the interface a cleaner design.

We wanted to retain the same universal features of the Menu access design as in the earlier phases but we wanted to make the items on the menu accessible. Therefore we created the radial menu that allowed faster access (predicted by Fitt's Law) to the items associated with the Menu. We called it "O". The current design of "O" [Figure 4] enables the tools to be accessed from any point around the tabletop and it is independent of the position of the driver.

Filter:

We wanted to add some more features to the Filter apart from just being used a tool for querying for sheets. We realised that the list box setup of the displayed sheets did not provide a sense of spatial layout of the sheets. We wanted to replicate the default layout of the displayed sheets and therefore designed the Sheet Quadrants [Figure 7] on the Filter. The sheet quadrants not only provide the names and the arrangement of sheets but also act a way of interacting with the Sheet Containers. We realised that our earlier interaction design between sheet names and the sheet container may be frustrating for team members during meetings. This can especially arise during situations when some team member wants to allocate a sheet to a container only to find that the container is on the other side of the table and therefore not reachable. Therefore, we decided to follow the current design of the Sheet Quadrants that provides a user with the sheet names allocated to a specific sheet container.

Linked View:

In this iteration of interaction design, we decided to display the specific drawing on the sheet that was related to a detail tag on the corresponding related sheet. This would help the users to visually identify the related diagram instead or visually querying for the diagram on the related sheet. We also decided to add an option for the users to choose the screen on which they want to display the related sheet. This was the final phase of the design of Linked View interaction and further details have been furnished in the Interface Design chapter.

Design changes post Pilot Studies:

We conducted four pilot studies to made changes to the prototype based on the observations from these studies. There was only one significant design change made based on the observations of the pilot studies. This change affected the Zoom window. Previous iterations of interacting with the zoom window involved “tapping” the zoom window in order to move the blue rectangular box. Pilot studies showed us that this kind of interaction did not promote a smooth interaction between the displayed view and the user. It was difficult to make small adjustments to the displayed sheet primarily because it only allowed careful “tapping” by the user on the zoom window. To get rid of this problem we changed the way the users interacted with the zoom window. We gave the interaction a smoother feel, by allowing the user to slide the blue rectangular box across the zoom window. This gave a translational feel to the interaction making the user feel as if he/ she is sliding the sheet across the screen.