Chapter 7
CubIT: Design and Evaluation of a Collaboration-Tool for Large Interactive Wall Surfaces

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Abstract In this book chapter we describe the design and evaluation of CubIT, a multi-user presentation and collaboration system installed at the Queensland University of Technology's (QUT) Cube facility. The 'Cube' is an interactive visualisation facility made up of five very large-scale interactive multi-panel wall displays, each consisting of up to twelve 55-inch multi-touch screens (48 screens in total) and additional very large projected display screens situated above the display panels. The chapter outlines the unique design challenges, features, implementation and evaluation of CubIT. The system was built to make the Cube facility accessible to QUT's academic and student population. CubIT enables users to easily upload and share their own media content, and allows multiple users to simultaneously interact with the Cube's wall displays. The features of CubIT are made available via three user interfaces, a multi-touch interface working on the wall displays, a mobile phone and tablet application and a web-based content management system. Each of these interfaces play different roles and offers different interaction mechanisms, appropriate to the underlying platform. Through its interfaces CubIT supports a wide range of collaborative features including multi-user shared workspaces, drag and drop upload and sharing between users, session management and dynamic state control between different parts of the system. The results of our longitudinal evaluation study showed that CubIT was successfully used for a variety of tasks, but also highlighted specific challenges with regards to user expectations as well as issues arising from public use.

7.1 Introduction

The Queensland University of Technology (QUT) recently opened an interactive exhibition and learning space as part of its newly established Science and Engineering Centre. The facility named 'The Cube' features five very large interactive

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multi-panel wall displays, each consisting of up to twelve 55-inch multitouch screens (48 screens in total) as well as very large projected displays situated above the display panels (see Fig. 7.1). The Cube facility constitutes a demanding real-world application environment. It is publicly accessible and has been designed to support large numbers of visitors, which include university staff and students, the general public and potentially large groups of visiting school students. Users can interact with a range of bespoke applications specifically built for the Cube [10].

CubIT, is a large-scale multi-user presentation and collaboration system, specifically designed to allow QUT's staff and students to utilise the display and interaction capabilities of the Cube. CubIT's primary purpose is to enable users to upload, interact with and share their own media content on the Cube's display surfaces using a shared workspace approach. Users can log into CubIT on any of the Cube's wall surfaces using their RFID-enabled (Radio-frequency identification) staff or student card. When they do so, they are given access to their individual user workspace. User workspaces contain media content which users have previously uploaded to the system, including images, video and text files, as well as custom-built presentations. Users can simultaneously open items from their individual workspace and display them on the shared multitouch canvas, as well as the large projection displays. Multiple users can share the canvas at the same time. Since the upload of user-generated content was a core requirement for the system, cross-device interaction was an important consideration in the early design process. CubIT supports user interaction across different devices and screen sizes. The system contains custom-build applications for smartphones and tablets that allow users to create content and easily upload it to the system, and instantly display it on the wall surfaces. Content can also be transferred between the multi-touch wall

Fig. 7.1 Two of the five wall displays in the Cube facility

surfaces and the very-large projection displays, enabling users to view content at different scales.

The design of CubIT, in the context of the Cube facility, posed a range of specific challenges, including:

- What is an appropriate conceptual design that makes use of the existing multiple large-scale multi-touch and projection surfaces to support the collaboration between multiple users?
- What are appropriate interaction mechanisms for large-screens that allow potentially inexperienced users to intuitively use the system?
- How can users be supported to effectively work across different interaction devices and surfaces?
- How do we address issues that arise from the fact that the system is situated in a public setting, including dealing with authentication and content moderation?

Some of the specific interaction techniques used in CubIT have been previously explored in a number of lab and "in the wild" studies (see related work). However, the scale and specific interactive capabilities of the Cube made it necessary to apply known concepts, like the shared desktop metaphor, to very large wall-sized displays in a public setting. In this book chapter we address resulting challenges and discuss how they impacted on the design, implementation and use of the system. We complement this reflection by discussing the results of a longitudinal evaluation study which examined the system's use, usability, user experience and use context. It is important to note that given the nature of the application context and its exposure to the public, CubIT has is not a prototypical development, but rather a fully operational system that has been used extensively over a nine-month period (between February 2013 and March 2014).

7.2 Background and Related Work

Multitouch-based interaction approaches have been studied in a wide range of settings such as collaboration (e.g. [5, 8]) and education (e.g. [14]). Recent advances in display technology, such as stackable thin-bezel LCD displays, have led to the availability of large, high-resolution multitouch displays that can be combined into very large, nearly seamless, interactive surfaces. These large interactive screen surfaces have opened a range of new opportunities, as well as challenges for the design of interactive applications. They allow application developers to create rich interaction environments that enable multiple users to simultaneously interact with digital content across large shared surfaces. There are a number of examples for systems that use very-large interactive screens in public settings. For instance, CityWall [9] was built to allow multiple users to interact with a given set of digital content on a large-scale, rear-projected, multi-touch wall display, installed in the city centre of Helsinki. Peltonen et al. [9] showed that users engaged in a rich

set of interaction practices and established social conventions to manage the shared screen real estate. Similarly, Schematic implemented a multi-touch wall display[1] that allowed participants of an international advertising festival to simultaneously log into the system using their RFID pass cards. Once authenticated users were able to browse schedules, access way-finding information and exchange social networking information. However, while both these applications support the exploration of a given set of predefined content, they were not designed to support the direct upload and interaction with user-generated content. There is further an increasing understanding of how people interact using large shared surfaces. For instance, Azad et al. [1] extended Scott et al's. [11] notion of territoriality to large vertical displays. While Scott et al's. original work focussed on relatively small shared tabletop surfaces, Azad et al. explored the collaborative use of space on large vertical surfaces in public spaces, for a given set of tasks. While the work highlighted common patterns of interaction, further work is needed to transfer the results to real-world collaborative environments with non-predetermined tasks.

While the availability very-large multi-touch surfaces is still a relatively recent phenomenon, the broader use of (large) interactive screens to support small-group interaction and collaboration has been extensively studied, in particular in the context of interactive meeting rooms and purpose build interaction labs. One particular focus of study has been the question how to use shared displays to facilitate the interaction between co-located users, and more specifically how to enable users to share application and media content contributed from personal computing devices, such as laptops. For instance, WeSpace [13] allowed multiple co-located users to jointly connect laptops 'on the fly' and share their desktop session in display environment consisting of a shared multitouch and a projection surface. Broughton et al. [4] extended this notion of collaboration and implemented a distributed 'blended interaction space' which supported the distributed collaboration between multiple groups of remote users via replicated tabletop setups combined with high quality vide-conferencing. Earlier research into "Multiple Display Environments" (e.g. [2, 6]) investigated small group collaboration across multiple devices and displays, however these setups generally use non-interactive shared displays. Users in these environments usually control shared application via their laptop mouse pointers. Such setups commonly employ a 'replication' approach, which allows users to share individual off-the-shelf applications or whole desktops on the shared display(s). However, other systems, such as Dynamo [6], implemented a different approach and instead provided custom content viewers, which allowed users to share content-specific information (e.g. URLs, media, documents) rather than whole applications. Both approaches have advantages and disadvantages. A 'replication' approach allows users to share specialised applications, that are specifically suited to a particular target domain. For instance, WeSpace [13] was designed to support collaboration amongst Astrophysicists. However, one particular drawback when implementing the 'replication/approach on multitouch screens is

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[1] http://www.possible.com/news-and-events/cannes-lions-touchwall.

that off-the-shelf applications, running on laptops, are almost exclusively single-user, single-mouse applications that are not optimised for the interactive capabilities and scale of large multitouch screens. By contrast, approaches, that support the sharing of content rather than applications are more widely applicable and can be specifically designed to utilise the interactive capabilities of the interactive surfaces they run on.

In addition to the question how to build systems that allow users to access and use their own (media) content, the question of how to implement such systems in a public environment poses additional challenges. Shen et al. [12], for instance, explored the use of collaborative multi-touch tables for ad hoc collaboration in public locations like airport lounges. The research featured the notion of a "walk-up" setup, highlighting the importance of being able to set up collaborative sessions and share content with relative ease and without the need for physical data or display connections. However, the work does not cover questions of content moderation and system access prevalent to real-work settings. Izadi et al. [6] studied how public displays could become a resource for multiple users to interact and share content. While the Dynamo system [6] shares many conceptual similarities with our approach, it differs across a range of dimension including technological setup (e.g. Dynamo used collaborative multi-pointer interaction of a public shared workspace controlled through laptops) and scale.

In summary, there is a large body of research that addresses various aspects of large-interactive screen and multi-device interaction in particular in the context of small group collaboration. However, the specific scenario described in this chapter, supports the collaboration of multiple simultaneous users on very-large multitouch wall surfaces in combination with mobile interaction devices, poses challenges that have not been addressed in detail. We will outline some of these challenges in the following section.

7.3 System Design

The overall design goal for CubIT was to make the Cube accessible to all of QUT's staff and students and allow them to display and interact with their own media content on the Cube displays. The motivation was based on early discussions with stakeholders who remarked that while the Cube was planned to feature custom-build applications and content it did not sufficiently support academic researchers to utilise the facility and showcase their own work. CubIT's vision was for the Cube to be become a system that supported "spontaneous walk up interaction and collaboration" on user-generated content. Given that the Cube display was situated in a public space the predominant purpose CubIT was seen as supporting the collaborative display of existing user-content to interested third parties, rather than supporting the collaborative generation of new content, a task that is more suited to non-public environments like meeting rooms and labs.

To address this overall design goal CubIT was developed as part of a user-centred design process that took into account feedback from a wide range of potential users, across different faculties, divisions and student bodies within QUT. The design context for CubIT was predicated on a number of factors. First, the Cube facility itself, in particular its layout, technical infrastructure, multitouch capabilities and public accessibility, had a large impact on the design of CubIT. This meant the system had to work on the different wall setups and include interaction mechanisms for both the multitouch as well as the projected displays. The fact that the facility was public-facing further meant that user authentication and content moderation became crucial. Second, the intended user base of QUT staff and students was very broad and involved a wide range of academic and professional backgrounds. As a result the intended system had to be generically applicable and usable even for casual users. Third, since the system aimed to support the upload of user-generated content, this process needed to be made as easy as possible and integrate cross-device support to allow users to use personal computing devices such as smart phones and tablets.

7.3.1 Functional Scope

Based on the design goal and reflection of the design context we built a series of low- and medium-level prototypes that were presented to potential users in two design workshops. Key technical and usage goals that defined the basic functionality were set early in the process to clarify the design scope. These key capabilities included:

- *Authentication*: Users should be able to authenticate and access their content, without having to use onscreen keyboards to type in their password.
- *Multi-user capable*: The multi-touch surface should support multiple users simultaneously using the system.
- *Ease of upload*: Uploading media content should be as easy as "flinging" content to the screen using a mobile device.
- *Sharing*: Users should be able to easily share content using the multi-touch screens.

In addition to these key capabilities we made a number of decision early in the design process, with regards to the way in which users would interact with the system. The design of the multi-touch interface followed a *messy desktop* metaphor, representing media content as scalable, rotatable and translatable widgets on a large canvas, which allowed users to move content around freely. Since the technology we used could not distinguish different users touching the screens, the system was built around the notion that content on the screen could be controlled by any user. With regard to representing user's media content, we decided to implement a localised, individually identifiable, content container per user, referred to as 'user

workspace handle'. Users would share the common canvas to display and interact with content, but access and manage their own content in their respective user workspace handles. Once a user had authenticated with the system their handle would appear on the shared canvas that displayed the username and avatar and allowed users to access their content. Lastly, we designed a number of basic features used to allow users to manage their content on the canvas, including the ability to hide all their content on screen, move all their content simultaneously to a different part of the screen, as well as manage their own workspace by reordering, adding and removing content.

7.3.2 Design Workshops

We ran two design workshops with prospective users of the system, in order to gather user requirements, discuss usage scenarios, receive feedback on low-level prototypes and discuss the potential functional scope of CubIT (see Fig. 7.2). The first workshop was run in February 2012 and consisted of 22 staff and students from a mix of faculties and divisions. The second workshop was held in March 2012 with 15 academics from the Science and Engineering faculty. Both workshops followed the same format and contained three sections. Section one consisted of an introduction of the existing mockups and prototypes (see Fig. 7.3) and a hand-on exploration of the capabilities of the multi-touch screens. The second session aimed to collect 'user stories' which envisioned how the Cube infrastructure and the CubIT concept could be leveraged it the participant's specific work context. Participants were split into small groups and invited to answer three questions with regards to the potential system: *"How does this relate to my work?", "How would this help you?", "What do I need it to do?".* The last section allowed participants to create paper-based prototypes that featured desired functionality.

The workshops resulted in a rich set of user stories and design concepts. The most commonly mentioned concepts that correlated with the design goals were:

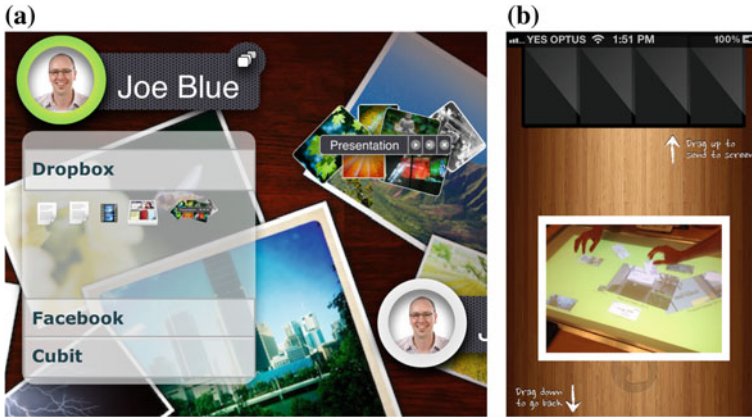
Fig. 7.2 First CubIT design workshop

Fig. 7.3 Mockups of the **a** multi-touch interface (*left*) and **b** mobile interface (*right*)

- *Top screen presentation*: Use the top screen (i.e. the projection display) for presentations (during times of activity) or auto-play content (during idle times).
- *Top screen dock*: A dock along the top of the multi-touch canvas allows users to push content to the top screen (projected). The content is iconised and allows users to control content on the otherwise inaccessible top screen.
- *Session*: Support sessions so users can create specific compositions of content and refer back to them. Open the last saved session when a user logs back in.
- *Demo user*: Create a dedicated demo user that contains interesting material and relevant public information. Users who are not authenticated can use the demo user to interact with the system.
- (*Mobile*) *Annotations*: Allow users to annotate content. A potential input mechanism is to use a smart phone/tablet.
- Rights management: Allow users to specify rights per content item (allow copy, share-alike, etc.)
- *Remote access*: Push content to remote locations (e.g. other campuses) and receive remote feeds (e.g. live lectures).

The outcomes of the design workshops informed the central functionality that was implemented.

7.4 The CubIT System

7.4.1 System Components

CubIT features three distinct user interfaces, each of which provides different functions and interaction mechanisms: a *multi-touch interface* running on the Cube large display walls, a *web-based content platform* and a *mobile interface*. The

web-based interface (implemented in Ruby on Rails) allows users to upload and manage content and further supports system administrators in the moderation of content and the administration of user accounts. The multitouch interface (implemented in Python using the Kivy[2] framework) enables users to interact with content on the large-scale multi-touch displays of the Cube and share content between users. The mobile interface (built in iOS, supporting iPhones and iPads) presents a mechanism to upload and create content on the fly. We will discuss each of these interfaces and the functions they support in detail in the next sections.

7.4.2 Multi-touch Interface

The CubIT multi-touch interface allows users to display and interact with the media content which they have uploaded to the system. Users log in by swiping their RFID card on one of the readers located underneath the multi-touch screens.[3] Once a user logs in, their user workspace handle (see below) appears on the shared workspace. The application is location-sensitive, the workspace handle appears on the screens that is associated with the closest RFID reader. This feature allows users to log out from one screen and move to a different part of the screen (or a different wall altogether) to log in again, effectively moving their content to different locations.

User workspace handle. The user workspace handle (see Fig. 7.4) represents a user's content in the system. It consists of an avatar, username label, scrollable workspace containing the media content and two function buttons, "pin/unpin content" and "minimise/maximise". The scrollable workspace displays the media content in the form of thumbnails. CubIT contains four different types of thumbnails for images, videos, text and presentations. Thumbnails can be dragged or clicked to be opened on the workspace. Thumbnails can also be dragged around the workspace handle to be reordered. An option to delete an item from the system is presented if a thumbnail is pressed for a slightly longer period of time (see Fig. 7.5a). The z-order for user handles is set to be higher than any other content on the screen ensuring that the user workspace is always accessible, and not obscured.

Media items. Media content items are *images*, *videos* or textual *notes* that appear as zoomable, rotateable and translatable widgets on the screen (see Fig. 7.5b). The zoom factor is limited to allow images to scale up to no more than the width of three portrait panels (3240 pixels) to prevent individual content items from obscuring the whole canvas. Videos can be played on-screen and have a standard set of video controls (pause, play, seek, volume). When opened from the workspace, each media item can be opened multiple times, spawning multiple instances on the canvas. If

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[2]https://kivy.org/.

[3]Each of the Cube's display walls is equipped with a number of RFID readers, generally one reader per 2 panels.
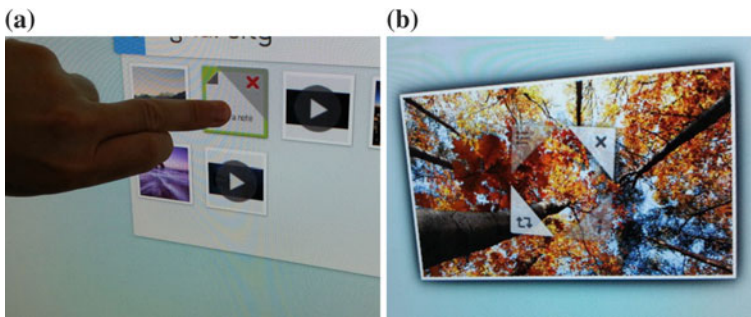
Fig. 7.4 CubIT interface elements

Fig. 7.5 **a** Delete item (*left*), **b** Media item with overlay sub menu (*right*)

items are permanently deleted from the workspace (or the system via the web interface) all of the items currently open instances of an item are closed. All content widgets use dragging physics to allow for content to be thrown. The friction settings are designed to limit the throwing distance to approximately 2–3 panels, preventing users from interfering with the workspace of users at the other end of a display wall.

Pinning. Each user workspace handle has a pinning button (see Fig. 7.4) allowing users to "pin" down the content relative to their handle and move all the content at once. This allows users to navigate the screen and move all their content to a different part of the screen while maintaining the relative content layout.

Minimize/maximize.   User   workspace   handles   further   contain   a minimise/maximise button as part of the item's overlay sub-menu (see Fig. 7.5b). Minimising content means that the widget is animated back into the handle. Minimise and maximise maintain the relative position and layout of media items.

The layout is saved as a session and is persistent across logouts. Sessions are shared between different instances of CubIT running on different walls. As a result, users can lay out their content in a particular way (e.g. for a poster presentation) and re-apply this layout to multiple setups (e.g. CubIT running on 3 different walls).

Presentations. CubIT includes a custom presentation widget (see Fig. 7.6) that allows users to display stacks of images, videos and notes in a more convenient manner. Presentations can be created using the web and mobile interfaces. The presentation widget contains several components. The display section allows content items to be displayed, scaled and swiped like a slideshow. The handle identifies the presentation. The selection box underneath the handle allows easy access to the surrounding slides and can be used to scroll through and navigate the presentation. Presentations can be edited dynamically using the multi-touch interface. In order to edit a presentation, users can press the presentation workspace button and open the presentation's workspace. A presentation workspace provides the same functionality as a user workspace and allows users to reorder, delete and add content on the fly.

Top dock and Top dock view. The layout and design of the Cube includes large projection screens on top of walls of interactive panels. As a result, each project implemented on the Cube had to find ways to design their system to make use of the projection screens while maintaining control over the interaction on the interactive touch panels below. In the case of CubIT, we decided to allow users to "throw" individual media item up to the projection screen to be displayed at full resolution. The rationale for this design option was to allow users to interact with content

Fig. 7.6   a CubIT presentation (*left*) and **b** presentation workspace (*right*)
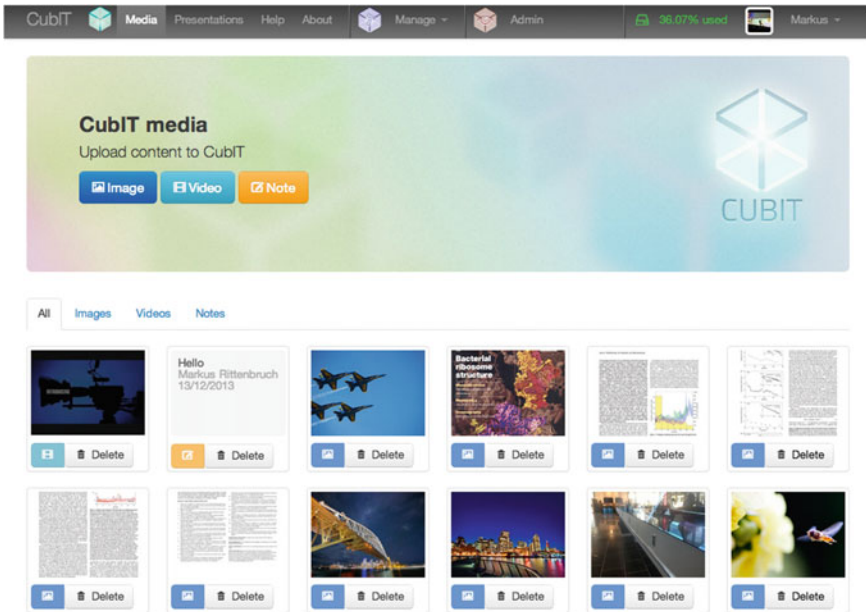
Fig. 7.7 CubIT web interface

closely on the touch panels, while using the projection surfaces for presentations to larger groups.

The mechanism in CubIT that controls the content on the top projection screen is called "top dock". It consists of a docking area stretching along the top border of the multi-touch panels. Media items that are dragged into the dock are displayed on the top screen. The top dock supports all media types images, note and videos, which auto-play when dragged onto the top dock.

Drag and drop sharing. The multi-touch interface supports sharing of content between users. In order to copy content items between accounts, users drag thumbnail representations of images, videos, notes or presentations into a different workspace. This creates a new instance of the copied object, which is now independent of the original. Because the system does not differentiate between users, objects can be freely copied between accounts by any user who touches the screen. To account for this, user accounts can be put into a "safe" exhibit mode to display of content over longer periods of time, in case users want to leave bits of content on screen for others to see (e.g. notice board).

7.4.3 Web Interface

The CubIT web-interface (see Fig. 7.7) is one of the two mechanisms allowing users to upload and maintain content on CubIT. The interface uses a standard user

registration and login system. As part of the registration process users can register their RFID cards allowing them to log into the system on the multi-touch wall. The web interface for a standard user account consists of two main sections. The "Media" section allows users to upload image and video content and create notes. Users can browse existing content and delete items. The "Presentation" section enables users to create and manage presentations. Users can add content already uploaded to the system to new and existing presentations, as well as delete existing presentations.

Further sections comprise a page specifying the location and installation instructions for the mobile application, an about page with general information about the project and an accounts page allowing users to change their user details and avatar image.

7.4.3.1   Admin and Moderator Roles

The web interface further supports two roles for users with elevated privileges, admins and moderators. For each of these role an additional section is displayed. Moderators can browse through all existing media content in the system and delete content and ban, unban or remove users. Moderators can set systems parameters like a user's data quota and change user's account privileges (e.g. promote to moderator, admin).

The moderator function was added to response to the potential issue of users uploading inappropriate content. The CubIT content is highly visible and potentially exposed to a large number of visitors. Moderation is conducted on a regular basis, after content gets uploaded. Moderation approval prior to uploading was not considered in order to allow users to upload content immediately, without having to wait for approval. If inappropriate content gets detected moderators have several options. They can remove the content and/or ban the user. Banned users will not be able to log into the any of the CubIT interfaces and receive a message informing them that they have been banned. Once the situation has been clarified, banned users can be reinstated. Moderators can further completely remove users from the system. Users who are being banned while they are logged into the multi-touch interface will be logged out and all their content is removed from the display.

7.4.4   Mobile Interface

The CubIT mobile interface is a native iOS application (see Fig. 7.8) which runs on iPhones (Fig. 7.8a) and iPads (Fig. 7.8b). The purpose of the interface is to allow users to easily upload content while away from their desks, and in particular, while standing in front of one of the touch screens. The mobile interface has four modes (represented by four icons at the bottom of the screen). Three of those modes are dedicated to different media types allowing users to upload images, videos, and

Fig. 7.8 CubIT mobile interface interface, **a** iPhone image upload (*left*), **b** iPad presentation creation (*right*)

notes respectively. The fourth mode allows users to change their avatar picture and log out of the application. The iPad version, due to its larger screen real estate, features an additional function. It allows users to create presentations from existing media sources and upload these presentations to CubIT. Users can scroll through their iPhone/iPad's media library in a scrollable section in the middle of the application. An "add icon" links to the device's camera application and allows users to create and upload content on the fly. The upload mechanism consists of a simple drag and drop mechanism. To upload, users drag images into the upload icon on top of the screen. An animation gives the appearance that the item is "sucked" into the screen and then uploaded. The upload mechanism has been designed to give the appearance of being able to "flick" multiple content items to the multi-touch walls.

In addition to its function as an upload device the mobile interface was also used as an input mechanism. As part of the design process it was decided that using on-screen keyboards on a shared multi-user display was likely to be less efficient, than allowing user to input text via their personal mobile devices. Thus the functionality that requires text input, such as notes as well as creating presentations, was implemented on the mobile as well as the web interface.

7.4.5 CubIT Collaborative Features

The system components described above have been designed to support co-located synchronous collaboration between users, within the context of the Cube. We summarise some of the collaborative features in turn:

Shared workspace and workspace control: Multiple users can share a large workspace canvas, where each user provides content using their user workspace handle. The system provides several mechanisms for users to manage the shared space. Users can "pin" their content and move it simultaneously to a different part of the screen. Users can minimize content, thus saving the layout of their current session and move it to a different part of the screen or a different display wall altogether. Interface elements have been specifically designed so that users can work together without obscuring each other's view of the workspace.

Drag and drop sharing: Users can simply share content by dragging and dropping content between user workspaces. This function extends to presentations by allowing users to create shared presentations on screen, with content provided by several users.

Easy upload from mobile devices: Drag and drop upload of content into workspaces allows users to dynamically add content to a shared workspace while working with others. Users can, for instance, capture the outcome of a joint discussion in an image or video and upload this directly to the shared workspace.

Dynamic state control between different parts of the system: The system dynamically synchronises state changes between the multi-touch mobile and web-interfaces. This allows users to dynamically update content on screen from a remote location (e.g. as part of a share co-located and remote design session).

7.5 System Setup

7.5.1 System Components

The CubIT system is made up of a number of system components (see Fig. 7.9). The *CubIT server* manages all aspect related to content and user management, including content upload (images, videos, notes), the creation of custom presentations, content delivery and maintaining workspace, session and authentication states. The CubIT *multitouch UI* manages touch interactions and widgets on the display panels, as well as the syncing and distribution of the interface's state across a series of multitouch screens and computing nodes. The *mobile UI* manages creation and upload of content as well as updates to user profiles.

The Cube's multitouch displays are driven by a series of graphics nodes, whereby each node drives two display panels. As a result the multitouch UI was implemented as a distributed application that is executed across a set of graphics nodes used to drive a particular wall surface. For instance, in case of a 12-panel wall the application is synchronised across 7 graphics nodes (2 panels per node plus one node for the projection screen).
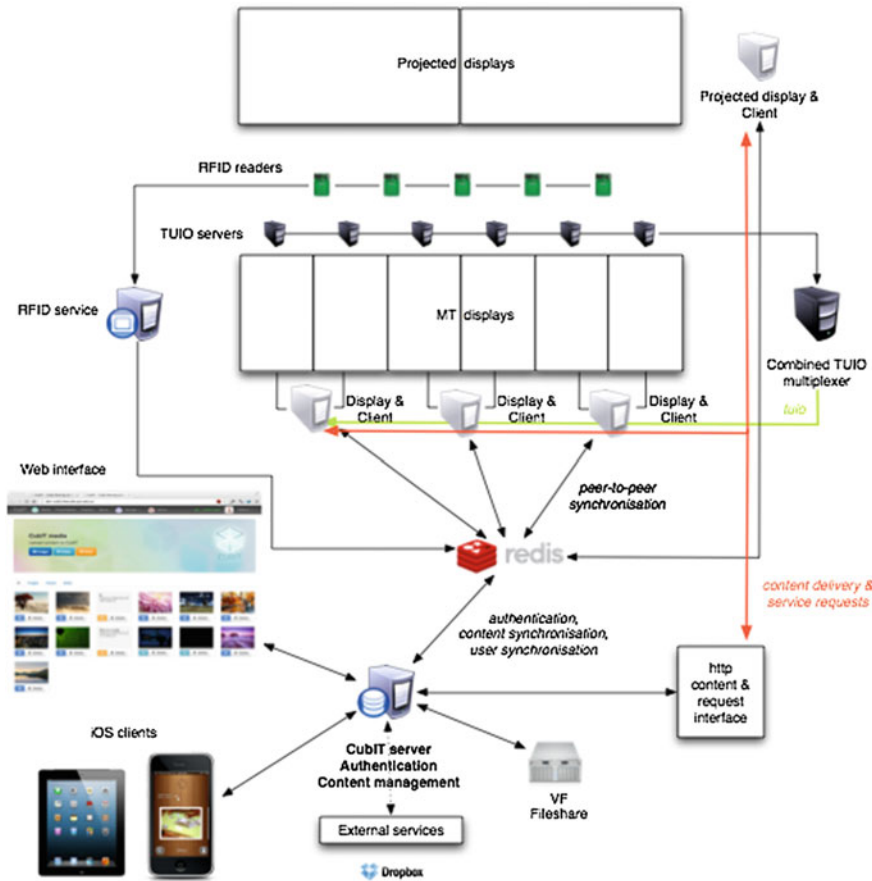
Fig. 7.9 CubIT system architecture

A *Redis server*[4] is used to maintain the consistent state of interface elements, send notifications between different system components and ensure a consistent state between the distributed graphics nodes that execute the multitouch UI. Each multitouch display panel has an integrated *TUIO server* recording touch events. These touch events get merged into a combined TUIO stream via a multiplexer, which flexibly reacts to the setup and number of CubIT instances running. The *RFID server* maintains the state of all RFID readers installed in the Cube and relays RFID event information via Redis to the CubIT server. The system diagram (see Fig. 7.9) is schematic and depicts a simplified version of our architecture, showing a single wall display consisting of 6 screens.

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[4]http://redis.io/.

7.5.2 System Runtime Setup

CubIT can be simultaneously deployed to any of the five wall surfaces of the Cube. The CubIT (web) server maintains the state of logins across walls allowing users to log into multiple walls simultaneously. This functionality is mostly useful in cases where content gets displayed to the general public, for instance during exhibitions or conferences (see 'exhibition user' functionality).

7.5.3 Organisational Setup and Use

CubIT was deployed in January 2013 and has currently over 550 registered users. Since its' release the system has been used for a variety of different purposes. We will briefly outline some of the uses that have been observed since deployment:

Teaching: CubIT has been used to present student work in a number of classes taught at QUT. Students were encouraged to sign up to CubIT and create their own account. They uploaded their project work and displayed it during critique and student presentation sessions.

Events and Conferences: CubIT has been extensively used during conferences and events. Conference use included the display of posters and general conference related information such as sponsorship slides, videos and other promotional material. Many organisers specifically used the top dock presentation, by designing content that fitted the maximum resolution of the screen and allowed them to present wide posters (e.g. see Fig. 7.10b, top).

Visitors and demos: CubIT has been commonly used by academics to showcase research and other content to visitors. Several users regularly showcase their content to (groups of) visitors, such as potential industry partners and collaborators.
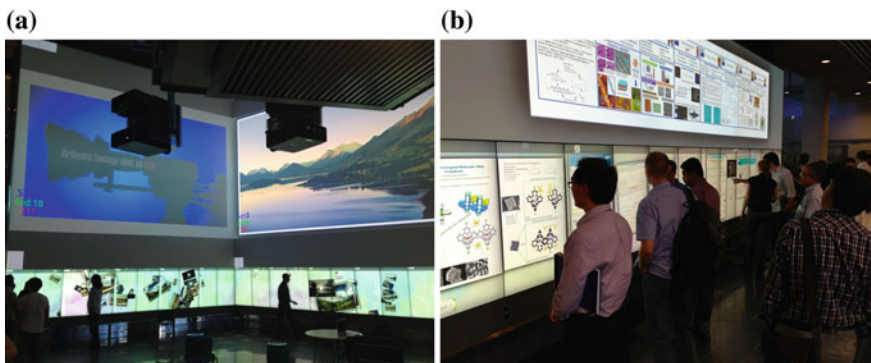
Fig. 7.10 Cubit on an **a** 20-screen (*left*) and **b** 12-screen wall surface (*right*)

School engagement: CubIT has been used as part of QUT's effort to engage school students. The school student program involved a guided tour of the Science and Technology Centre as well as the participation in various workshops and activities. These activities were documented by educators and uploaded to CubIT for students to browse.

It is important to note that as the Cube is a multi-purpose facility the software displayed on each of the wall surfaces, including CubIT, is subject to scheduling. During the usage period covered in this chapter (January–September 2013) CubIT was generally available by default on at least one of the wall surfaces and would run on other surfaces on request. However, scheduling could lead to situations where CubIT was not available when or where users expected it.

7.6   System Evaluation

7.6.1   Study Design

The study took place approximately 9 months after the system had been made available for public use in early 2013. Study participants were recruited amongst the 470 users who had signed up to use CubIT at that point in time. CubIT user consisted of QUT academics, professional staff, and students. An email was sent out to all users to invite them to participate in a 20-item questionnaire on the use, usability and user experience of CubIT. The questionnaire was open for 2 weeks and 48 participants completed the questionnaire. To protect the participant's privacy and to counter any potential demand characteristics effects the study was fully anonymised, so that the identity of participants could not be determined by the researchers conducting the study.

The questionnaire consisted of four different sections, *general information*, *system use*, *user experience* and *use context*. The *general information* section covered basic information about the background of the participants. The *system use* section queried which of the various aspect and functionalities of the system participants had used. The *user experience* section covered a range of usability and user experience measures. Last, the *use context* section consisted of questions that explored for which tasks the system had been used and contained open questions to determine attitudes towards the use of the system.

The user experience section contained a series of questions which were based on SUS (System Usability Scale) [3], a widely used usability questionnaire. We added one additional question in this part of the questionnaire, which queried participants' perception of the availability of CubIT on the Cube's wall surfaces (based on scheduling in the Cube). In addition to the usability questions, we ran a set of question relating to the user experience using UEQ (User Experience Questionnaire) [7]. Both, the usability as well as the user experience instruments were of a general nature and did not specifically target the multi-user or multi-touch

capabilities of the application. However, they were coupled with a set of open-ended questions relating to people's experience with the system which allowed for a broader, qualitative assessment of the results.

7.6.2   Results

7.6.2.1   Functionality Use

We asked participants to rate whether they had used different functionalities of the system. The answers included *yes*, *no* and *do not know how* options.

The results (see Table 7.1) show that the fundamental functions of the system (how to sign up, log in, upload and display media content) were known to almost all users. More than half of the users had used functions to manage content on the screen (delete content, display presentation, used the pin button, etc.). And a smaller subsection of users had used the mobile features and installed the mobile app as well as uploaded content from their mobile device. Surprisingly, relatively few users had used the system to share content by dragging it to or from other user's workspaces to their own workspace (23 % and 10.5 % respectively).

7.6.2.2   User Experience

Tables 7.2 and 7.3 summarise the results of the usability and user experience evaluation of CubIT, ordered by mean values. All items were rated on a scale between 5 "strongly agree" and 1 "strongly disagree".

SUS and UEQ include both positively and negatively worded item. While we used alternating questions in our questionnaire, we inverted the scores and wording of the negative items when reporting our results, to achieve better comparability (inverted items are marked in both tables).

The outcomes of the usability evaluation were generally positive. A majority of participants felt that the system was easy to use and felt confident in using it. The question that received the most positive answers was whether CubIT should run on the Cube more often.

The participants on average agreed that the system meets all positive user experience factors. *Innovative* and *enjoyable* were the two highest rated items with a median of 5. All other factors with the exception of *secure* and *predictable* were rated with a median of 4. *Secure* received the lowest median score of 3. *Predictable* received the second lowest score with a median value of 3.5, indicating that the system was on average perceived to be just slightly more *predictable* than *unpredictable*.

Table 7.1 CubIT functionality use

Question	% Yes-No-Do not know how (n/a)
Logged into one of the display walls at the Cube using your QUT staff/student card	**92**-8-0 (0)
Signed up to CubIT using the web interface	**92**-8-0 (0)
Used CubIT on one of the display walls at the Cube	**90**-10-0 (0)
Used the web interface to upload media content	**85**-13-2 (0)
Dragged media content into the top dock	**81**-17-2 (0)
Used the minimise/maximise button	**79**-19-0 (2)
Used your workspace handle to open and display content	**77**-19-4 (0)
Used the CubIT web interface	**77**-19-0 (4)
Used the web interface to delete content	**58.5**-33.5-2 (6)
Used the pin button	**52**-36-6 (6)
Reordered content in your workspace	**52**-35.5-10.5 (2)
Displayed a presentation	**52**-42-4 (2)
Deleted content from your workspace	**50**-37.5-10.5 (2)
Used the mobile app to upload images or videos to CubIT	**38**-54-2 (6)
Used the web interface to create notes	**35.5**-54-6.5 (4)
Used the web interface to create presentations	**33.5**-54-8.5 (4)
Downloaded and installed the CubIT mobile iPhone app	**31**-61-2 (6)
Used the mobile app to upload content while standing in front of a CubIT display at the Cube	**31**-56-6 (6)
Used the web interface to delete presentations	**29**-56-11 (4)
Downloaded and installed the CubIT mobile iPad app	**25**-67-2 (6)
Copied content from another user's workspace into your workspace	**23**-60.5-14.5 (2)
Used the mobile app to create notes and upload them to CubIT	**17**-71-4 (8)
Copied content from your workspace into another user's workspace	**10.5**-71-14.5 (4)
Used the mobile app to change your avatar picture	**8**-75-11 (6)

7.6.2.3 Use Context

We asked participant to select multiple ways in which they used the system from a number of predetermined alternatives. The selection contained an open question allowing the participants to specify "other" activities. Table 7.4 shows the chosen activities in order of preference.

There was one entry for "other" activities, which indicated that the system was used as part of a *"high school competition"*.

The most common reported uses of the system included displaying own content, either generally, to colleagues, external visitors or as part of a presentation. About a third of the participants had left content on the screen for others to see. About 20 % had used CubIT as part of a conference presentation. The two activities that scored lowest were *exchanging content with others* and *giving a lecture*. The relatively low rate of participants who used the system to exchange content with other users

Table 7.2 Usability evaluation (SUS) results

Question	Med. (SD)	Mode	Mean
I think that CubIT should be running on the Cube more often	4(0.96)	5	4.07
I thought that CubIT was easy to use	4(1.06)	5	4.00
I did not find CubIT very cumbersome to use [inverted]	4(1.13)	4	3.84
I do not think that I would need the support of a technical person to be able to use CubIT [inverted]	4(1.39)	5	3.82
I felt very confident using CubIT	4(1.17)	5	3.80
I would imagine that most people would learn to use CubIT very quickly	4(1.18)	4	3.73
I did not find CubIT unnecessarily complex [inverted]	4(1.30)	5	3.73
I did not need to learn a lot of things before I could get going with CubIT [inverted]	4(1.4)	5	3.67
I am likely to use CubIT [inverted]	4(1.35)	5	3.62
I did not think there was too much inconsistency in CubIT [inverted]	3(1.12)	3	3.54
I am likely to share content with others using CubIT [inverted]	4(1.34)	5	3.51
I found the various functions in CubIT were well integrated	4(1.23)	4	3.43
I think that I would like to use CubIT frequently	3(1.38)	5	3.33

Table 7.3 User experience (UEQ) evaluation

Question	Med. (SD)	Mode	Mean
Innovative/conservative	5(1.09)	5	4.35
Enjoyable/annoying [inverted]	5(1.23)	5	4.16
Creative/dull	4(1.00)	4	4.07
Attractive/unattractive	4(1.06)	5	4.05
Exciting/boring	4(1.12)	5	4.00
Practical/impractical [inverted]	4(1.33)	5	3.88
Organized/cluttered [inverted]	4(1.16)	5	3.86
Clear/confusing [inverted]	4(1.18)	5	3.84
Efficient/inefficient [inverted]	4(1.21)	5	3.79
Fast/slow [inverted]	4(1.30)	5	2.64
Supportive/obstructive	4(1.14)	4	3.53
Secure/not secure	3(1.22)	3	3.26
Predictable/unpredictable [inverted]	3.5(1.45)	5	3.24

matches our observation, that the sharing function was only used by at most 23 % of participants. A total of two participants specified that they used the system to deliver a lecture.

Table 7.4 Activities CubIT was used for

Question	% Yes	% No
To display your own content	66.67	33.33
To test CubIT and understand how it works	64.58	35.42
To present content to colleagues/fellow students	58.33	41.67
To present content to a group of people	45.83	54.17
To present content to external visitors	41.67	58.33
To leave content on the screen for others to see	35.42	64.58
To display content as part of a conference/seminar	20.83	79.1
To exchange content with other users	10.42	89.58
To give a lecture	4.17	91.83

The second part of the use context section consisted of a series of open questions asking what people liked best and least about the system, as well as an open question that allowed participants to comment on their use of the system. We used a grounded theory approach to analyse the qualitative data and conducted open coding on the set of answers in order to determine relevant concepts and categories to structure the results. Answers to the question *"Do you have any other comments about CubIT, or this questionnaire?"* closely mirrored answers received in the questions regarding best and least liked aspects of CubIT and were coded together with these question.

7.6.2.4 Best Liked Aspects of CubIT

Regarding the question: *"which aspects of CubIT did you like best"*, we identified the following categories, which are ordered from most to least relevant.

Presentation of content: This category received the highest number of mentions across all participants. Participants generally appreciated being able to use CubIT to present content to colleagues and the general public. The category covers the general ability to present to different audiences as well as the ability to simultaneously display many content items on a the wall displays.

Interactive capabilities: The second most relevant category relates to the interactive capabilities that CubIT offers. Participants appreciated the scalability of content, moving content across different surfaces, support for different media types and being able to physically manipulate content through the multitouch interface.

Flexibility and openness: This category relates to the flexibility and openness of the system. These aspects were related to ability to display different content and use CubIT on different screen configurations. Participants also perceived that the system had many different uses. One participant remarked: *"CubIT can turn from an academic board to a social networking board instantly, depending on who is using it. As a social networking board, I love it."*.

Scale and wow-factor: The fourth-most relevant category is related on the impact that CubIT had on users and visitors. The size of the screen displays played and

important role in how users perceived the system. One participant opined: *"CubIT's size is impressive. It's large enough to get anyone excited about using it"*. In addition to the screen size, CubIT was perceived as "cutting edge". Another participant mentioned: *"Its like Iron Mans office!"*.

Ease of use: The last category that received frequent mentions is how easy the system is to use. This includes numerous comments regarding the simplicity of use of the multi-touch interface, as well as the easy authentication via RFID Cards.

In addition to the categories mentioned above there are a number of other categories that were of relevance, but were overall less common. These include: *Multi-user capabilities*—Supporting multiple users at the same time; *Web and mobile integration:* Content upload via different interfaces; *Remote repository:* The notion of using CubIT as a remote repository for content accessed by ones' staff/student card.

7.6.2.5 Least Liked Aspects of CubIT

Regarding the question: "**which aspects of CubIT did you like least**", we identified the following categories. Like in the previous section, the categories are ordered from most to least relevant:

Interface improvements: This was the most commonly mentioned category, which related to a varied range of requests and suggestions to improve aspects of the user interface(s) and the overall system functionality. The issues mentioned were very diverse with no clear trend indicating one specific area that was of more pressing concern than others. The issues ranged from controlling video playback volume, additional remote presenter functionality for the top dock, to requests to allow users to reset passwords and RFID Card IDs.

Public use: A diverse set of issues arose around the public use of the system. The reported issues ranged from privacy and security concerns, to concerns about inappropriate content and behaviour to the question how suitable the public space is to deliver lectures. One participant raised their concern regarding inappropriate use of the system: "*Other people unrelated to our course/presentation playing loud, intrusive and offensive content during the time we were using it*".

Creation: One of the more common requests for additional functionality centred around tools that allowed users to create and annotate content directly on the multi-touch screen. The most mentioned functions were "interactive whiteboard" and "annotation of media items".

Media types: There were a number of requests for the system to support additional media types, such as Word documents and Web pages.

Reliability: some users reported reliability issues ranging from the feeling that elements were "freezing" to system crashes.

Availability: The next commonly mentioned category related to an organisational matter. Some participants commented that they would have liked to be CubIT to be more regularly available in the Cube or be available on a different screen/wall setup.

Other categories were mentioned occasionally. Some participants requested to make an *Android mobile* application available. Other participants made comments regarding the availability of *documentation*. These comments did not refer to the availability of general system documentation, but requested information about specific uses, e.g. how to use the system in the context of a particular class: "*No documentation I can get to guide me through how I might integrate it with my unit. Or run an assignment. This may be because it has not been used in this way previously*".

7.7 Discussion

The results of the study revealed which system functions were most commonly understood, how its usability and user experiences were rated, in which context the system was used, and which aspects of the systems and its use were most liked or disliked. The results generally indicated that CubIT fulfilled its purpose. However, there are a number of more subtle aspects that highlighted challenges related to the public use of the system and its ability to implement a wide range of functions, yet remain intuitive and flexible.

7.7.1 Usability, User Experience and Context

Regarding system use, the study showed that the majority of participants appreciated and had used the fundamental system functions. In particular functions related to the presentation of, and interaction with, media content on the multitouch screens were well understood. Surprisingly, two collaborative functions, the sharing of content by dragging it to or from other user's workspaces scored comparatively low. This matches the results from the "use context" part of the study, which showed that "*to exchange content with other users*" was the second least commonly engaged activity amongst our participants. Two other use aspects that scored low were the use of the mobile app to create and upload notes and changing the avatar picture via the mobile interface. While we predicted the latter function was likely to be used occasionally, the copying content functions and upload of notes were considered core functions during the design process.

One possible explanation for the lower than expected use, lies in the deployment strategy. As a side effect of the 'word of mouth' strategy, users received no formal training in the use of the system. While the system functions were generally perceived as being intuitive, some functions, like the ability to copy content between user workspace handles had to be discovered. An online manual was available through the web-interface, which covered this and many other functions. However, it is possible that this "cross-device" help approach was too removed from users who were interacting with the multitouch interface. Interestingly, we frequently

observed that existing users would explain the system to their friends, but these explanations were often limited by what the explaining person knew about the function of the system.

The outcomes of the usability and the user experience evaluation were overwhelmingly positive. The number of positive responses to the question as to whether CubIT should run on the Cube more often, indicates that many of the participants were interested in using the system regularly. While availability is an obvious requirement for a 'walk up and use' system like CubIT, the system could however not always be made available, due to the multi-purpose nature of the Cube facility.

The results regarding the use context of CubIT closely matched the suggested categories. The most common reported uses of the system were those that matched the anticipated use of the system and represented its core functionality. Using the system to deliver lectures was uncommon, since all screens were in publicly accessible areas with significant amounts of thoroughfare and only public lectures would have been considered appropriate. This sentiment is mirrored by comments participants made regarding the public use of CubIT.

7.7.2 Public Use

The qualitative evaluation of CubIT resulted in rich set of categories. Some of the most interesting were *Flexibility and openness, Scale and wow factor, Public use, Creation and Media types*.

The *Flexibility and Openness* of the system was appreciated by most users and matches the fact that the system was perceived as usable, intuitive and well integrated. These aspects lead us to conclude the design goals of providing easy and intuitive access to the Cube and allowing users to interact with their own media content have been met. Comments made with regards to *Scale and wow factor* indicated the CubIT has used the display infrastructure of the Cube efficiently and that the scale of the interaction had a significant positive impact on the user experience.

Issues surrounding *public use* highlighted some of the tensions that can arise when placing an open user-generated content platform in a public space. The comments regarding the inappropriate behaviour of some users were particularly interesting. There is an obvious trade-off between the risk involved in managing content in a public environment and giving users the freedom to directly upload and interact with content on the display surfaces. Content moderation was implemented as part of the web-backend of CubIT. However, a conscious decision was made, not to moderate content upfront in order to give users the experience of "immediacy" when uploading content to the system. This strategy generally worked very well. Only one known case of inappropriate content had to be dealt with during the trial. We attribute this low number of incidents to the fact that all users of the system were identified by their QUT email address, which was required to sign up to the

system. However, this strategy did not help to prevent the 'inconsiderate behaviour' reported by one of the participants.

7.7.3 Functional Scope Dilemma

Creation and *media types* were related categories that highlighted the challenge of building a generically applicable system for a diverse user population. Some participants requested both specialised tools (e.g. whiteboard functionality) and additional media formats (e.g. Word documents). A conscious decision was made early in the design process to limit the number of potentially complex functionality the system offered in favour of easy-to-understand functions (upload, display, present and share). While functionality like electronic whiteboards have been successfully implemented in electronic meeting rooms environments, they do add additional complexity and modalities to the user interaction, in particular when added on top of multi-user workspaces. Similar challenges arose from request for additional media content. While these requests were understandable they opened up the system to a multitude of integration issues. They would have required the integration potentially proprietary viewers (e.g. Microsoft Word viewer), and a modal interface that would switch the focus between the viewer and the workspace. Very few proprietary viewers have been designed for multitouch input or are likely to be consistent with the multitouch gestures used in CubIT. The challenge in the further development of CubIT and comparable systems is to integrate additional collaborative functionality within a consistent interaction framework that is suitable for casual users, does not require multiple modes of interaction and supports the simultaneous interaction of multiple users within a large shared workspace.

7.8 Conclusions

This chapter described the design, implementation, use and evaluation of CubIT, a large-scale, multi-user collaboration and presentation system. CubIT was specifically built to allow a broad user population to upload user-generated content to the Cube's interactive surfaces. Thus the systems' design not only had to take into account the Cube's physical and technical setup, but also define interaction paradigms that would allow casual users to jointly interact with and share content across a large shared multitouch canvas, as well as integrate interaction across different devices and surfaces, at different scales.

The resulting system was implemented across three user-interfaces: each of which fulfilled a different purpose. The multitouch interface was designed to allow users to display content on large-scale displays, authenticate with ease using RFID, present content to larger audiences on very large-scale projection surfaces, and easily share content across user accounts using various widgets and multitouch

interaction mechanisms. The mobile interface was designed to provide textual input, allow for the grouping and creation of content (notes and presentations) and specifically, to allow users to upload content to the wall surfaces by 'flinging' content to the screens. Lastly, the web-based interface supported the same functionalities as the mobile interface. It, additionally handled user management tasks (authentication, user management, quota), help, and content management and administrative tasks for selected system administrators.

The evaluation of CubIT revealed that the system was generally perceived positively. It also highlighted some conceptual challenges, particularly questions related to the public use of the system, and managing the expectations of a broad user base as to what functionality the system should support. While CubIT has been built within the specific context of the Cube, we believe that many of its design and interaction principles, as well as the lessons learnt from the evaluation, transcend the physical setup and can be applied to different contexts and systems. We hope that software designers who develop systems for similar settings can learn from our experiences.

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