# Effect of User Roles on the Process of Collaborative 2D Level Design on Large, High-resolution Displays

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Abstract: This paper presents groupware to study group behavior while conducting a creative task on large, high-resolution displays. Moreover, we present the results of a between-subjects study. In the study, 12 groups with two participants each prototyped a 2D level on a 7m x 2.5m large, high-resolution display using tablet-PCs for interaction. Six groups underwent a condition where group members had equal roles and interaction possibilities. Another six groups worked in a condition where group members had different roles: level designer and 2D artist. The results revealed that in the different roles condition, the participants worked significantly more tightly and created more assets. We could also detect some shortcomings for that configuration. We discuss the gained insights regarding system configuration, groupware interfaces, and groups behavior.

## 1 INTRODUCTION

Large, high-resolution displays (LHRDs) are highly suitable for collaborative work. Due to their large size and a vast amount of pixels, they allow visualization of large data sets. They foster the exploration of data sets through intuitive and effective physical navigation (Ball et al., 2007; Rädle et al., 2013); they allow users to better overview the content, and to make use of spatial memory while searching for items on the display (Andrews et al., 2010). Additionally, the large size provides much better support for multi-user support in comparison to standard desktop displays.

Polley and McGrath (1984) listed four collaborative task types: planning, creative, intellective, and contest. The creative process was investigated on LHRDs to a limited extent only. The tasks used in the previous research set constraints that did not allow to unfold creativity. For instance, jigsaw composition (Azad et al., 2012; Scott et al., 2003), text composition (Ryall et al., 2004), the arrangement of photos (Hinrichs et al., 2006), outline task (Tse et al., 2004), or interior layout planning (Scott et al., 2004), allowed only to layout assets, but not create them. Additionally, in the case of the jigsaw and text composition, the outcomes were more or less predefined. Moreover, researchers investigated the creative process mostly on tabletops. On the vertical displays, the analytical process was more in focus, e.g., Andrews et al. (2010), Vogt et al. (2011).

In this work, we developed groupware (collaborative software that allows multiple users to work on a common task) to support and investigate the 2D level design process on LHRDs using tablet-PCs for interaction. The process combines at least two collaborative tasks: planning and creative. The groupware allows not only to place/layout assets but also to create them. We also conducted a study to evaluate the developed groupware in combination with our LHRD. We assessed users attitude towards the system, analyzed the usage of the system, and looked into behavioral patterns in terms of territoriality, collaborative coupling, and workspace awareness.

Previous research detected that during collaboration on LHRDs users occasionally undertake different roles to approach the task in a more efficient manner (Vogt et al., 2011; Rogers and Lindley, 2004). As a result, researchers suggested to consider user roles when building groupware and provide groupware mechanisms that will support them. One possibility to support user roles is to provide interfaces that consider all possible roles and allow for dynamic switching between them. Another way is to provide different interfaces where each interface focuses on a specific role. In both cases, users must coordinate themselves to distributed roles as needed. However, in the case of universal interfaces, coordination is vol-



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untary and therefore, might never take place. Specialized interfaces, on the other hand, might be perceived as too restrictive and awkward, similar to Rogers and Lindley (2004).

In our study, we investigated the effect of different interface types on the collaboration process. Twelve groups two participants each participated in the study. All groups had the same task. However, the participants of the first six groups had the interface which allowed them to create tiles and place tiles on the LHRD. Thus, the participants could decide on their own who will undertake what role in case they decided to distribute the roles. The participants of the other six groups had different interfaces which either allowed to create assets or to place them. Thus, the participants had to undertake a specific role.

Our contribution is twofold. First, we present a groupware system for collaborative level design on LHRDs. The system is based on the Unity engine and could serve as basis groupware not only for level design tasks but also for other creative tasks. We provide the results of the evaluation, as well as insights regarding the acceptance of the system setup and level design task in the given system environment. Second, we provide insights regarding the effects of the explicit distribution of user roles on the process of collaborative 2D level prototyping. The results could be generalized to any other collaborative design process on LHRDs.

Our research extends the theoretical basis and improves understanding of collaborative processes during creative work on LHRDs. It reveals and categorizes behavioral patterns of groups and provides knowledge of how group behavior can be guided. Additionally, it provides insights useful for the professional practice of building collaborative systems and groupware for creative tasks.

## 2 RELATED WORK

In this section, we provide a brief overview of research that considered planning, creative tasks, and games on LHRDs, as well as research that investigated group behavior during co-located collaboration on LHRDs.

**Planning and Creative Tasks on LHRDs.** Azad et al. (2012) conducted a controlled experiment where the participants had to solve jigsaw puzzles in non-collaborative and highly-collaborative configurations. They looked into on-display behavior, off-display behavior, and combined behavior. As a result, they could develop some guidelines for groupware design regarding territoriality and reaching and sharing interactions.

Jakobsen and Hornbæk (2016) conducted a study on an LHRD comparing touch input to mouse input. The study consisted of two tasks: the newspaper task and the puzzle task. In both tasks, participants had to layout either puzzle pieces or articles. They found that LHRDs can enable equal participation regardless of input, yet touch input can frequently become an interference source.

Liu et al. (2017) executed a study where the participants had to find similarities or connections between the pictures and arrange them in a meaningful way. They used the scenario to evaluate touch gestures for cooperative work. They also enabled users to perform the gestures on multitouch tablets, thus allowing for indirect interaction. However, remote gesturing was not accepted well by all participants.

Some other researchers investigated layout tasks in tabletop environments. For instance, Ryall et al. (2004) let the participants assemble target poems using word tiles. The focus of the study was on the effects of the table size on social interaction and the effects of the group size on task performance and work strategies. Another study with a layout was conducted by Scott et al. (2005). In this study, they evaluated a storage bin mechanism for passing objects in tabletop environment.

The research of planning and creative tasks on LHRDs shows that 2D level prototyping on LHRDs is possible and worth investigation. However, many questions regarding interaction, visualization, and handling of social phenomena are open and require answers. Moreover, many studies considered creative and planning tasks isolated from a context. Thus, researchers must investigate how the combination of proposed visualization and interaction techniques will perform together.

**Gaming on LHRDs.** Sabri et al. (2007) implemented one of the first LHRD games, which was a real-time strategy game. They run the game on a display that consisted of nine displays arranged in a 3x3 matrix with a total resolution of 8 Megapixels. They compared gamers performance on the LHRD to the performance on smaller displays, investigated usability issues, and evaluated different display form factors and input possibilities. The results revealed that players performed significantly better on the LHRD in comparison to standard desktop displays.

PyBomber, developed by Machaj et al. (2009), is, to the best of our knowledge, was the first multiplayer LHRD game. The game run on the GigaPixel display that consisted of 50 displays with a total resolution of 96 Megapixels. Machaj et al. (2009), used the game to investigate the effect of the LHRD environment as well as different player configurations on social interactions and physical navigation. They could observe a shift in social dynamics with an increasing number of players. Additionally, they provided some guidelines for the design of LHRD games.

Miners is another multiplay game for touch-sensitive LHRDs developed by von Zadow et al. (2016). Miners is a fast-paced, collaborative game that must be played precisely by four players. Each player has a unique role with specific abilities in the game. It is a cooperative game, which means that the players have to bundle their forces to beat the game. The participants found the game enjoyable and exposed a high level of engagement. The observation results showed as well that participants suffered from limited awareness of other participants because of the employed interaction technique that allowed only for direct interaction with the display from up close.

The studies show that gaming on LHRDs not only possible but also well accepted by players and makes fun. Thus, it represents a potential new development branch for computer games. The prototyping process of game levels for LHRDs on standard desktop displays might be tedious because of the small workspace they provide. Therefore, it can be of advantage to develop LHRD groupware that will allow for level prototyping directly on LHRDs.

**Territoriality.** In the context of computer-supported cooperative work, territoriality aims for allocation of particular workspace areas for particular activities, for own work, and assets protection, e.g., Isenberg et al. (2010), Scott et al. (2004), Tang et al. (2006).

Tang (1991) conducted one of the first researches on territoriality in the context of CSCW. Two territory types were detected: group and personal. Later, Scott et al. (2004) conducted an extensive study within a non-digital tabletop environment to gain a deeper understanding of territoriality. As a result, they detected a new territory type: storage territory. Additionally, Scott et al. described in detail the characteristics of individual territory types. Many other researchers investigated territoriality in tabletop environments, e.g., Tang et al. (2006), and some interactions techniques were introduced, e.g., Moellers et al. (2011), Scott et al. (2005), to support this concept.

Significantly less research on territoriality took place in the context of vertical displays. Azad et al. (2012) investigated territoriality on public wall-sized displays. In addition to the known territory types, they detected a new territory type that describes display regions avoided by the user. They called these territories unused. Jakobsen and HornbÆk (2014) observed territoriality on a large, vertical display. They noted that participants frequently worked in parallel without negotiating for space and shared the display evenly. They also stated that territories are more critical for loosely coupled work than for tightly coupled. Wallace et al. (2016) conducted an empirical study where they explored users' personal spaces around large public displays and confirmed the emergence of different territory types.

Previous research shows that users tend to apply territoriality even if no explicit tools are provided and that users able to handle territoriality using social protocols and norms. However, the concept of territoriality is still not well understood. In particular, it is not clear if the concept has a significant impact on intra-group interactions and if it should be considered during the design process of collaborative systems. On the one hand, providing supporting tools and techniques might make the system more user-friendly. On the other hand, implemented rules and workflows might limit the interaction freedom of the user resulting in decreased acceptance of the system.

**Collaborative Coupling.** Collaborative coupling describes the process of user-user interaction for task accomplishment and can be expressed, among others, through collaboration tightness, coupling styles, user roles, and task subdivision strategies. In general, researchers subdivide collaborative coupling into two ranges: tightly and loosely (Gutwin and Greenberg, 1998; Morris et al., 2004; Tse et al., 2004; Gutwin and Greenberg, 2002). Within these, the intensity level may vary depending on a coupling style. Originally, tightly coupled work was defined as work that barely could take place without user-user interaction, while loosely coupled work describes rather a workflow where users act independently, e.g., Gutwin and Greenberg (1998, 2002), Salvador et al. (1996).

Tang et al. (2006) adjusted the term collaborative coupling as how "collaborators are involved and occupied with each other's work" to highlight social aspects of the phenomena. They conducted two observational studies in the context of the collaborative exploration of fixed spatial data around tabletops. They could detect and describe six coupling styles the groups used during the work (e.g., same problem, same area).

Following, Isenberg et al. (2010) conducted another exploratory study around a tabletop system, where participants had to analyze 240 documents. The study revealed eight different coupling styles that were described based on participants' data view and personal interactions.

Jakobsen and HornbÆk (2014) recreated the exploratory study of Isenberg et al. (2010) using a multitouch wall-sized display. Jakobsen et al. used codes for visual attention and verbal communication to describe coupling.

Rogers and Lindley (2004) investigated group behavior around both vertical and horizontal interactive displays. They observed that in the vertical display scenario, the participants more frequently transitioned to loosely-coupled work in comparison to the horizontal display scenario. They could also observe the interactor user role (the person who interacts with the system).

Vogt et al. (2011) investigated group behavior during collaborative sensemaking on an LHRD. They described group behaviors concerning activities (e.g., extract and cluster) and user roles. In total, they identified two user roles: sensemaker and forager.

Collaborative coupling is a useful tool for description and understanding of intra-group behavior. Extraction of collaborative coupling patterns might open a possibility to create adaptive collaborative systems (Sigitov et al., 2018). These systems will be able to recognize intra-group states and adjust automatically internal parameters to provide better support for individual states. Another research direction would be to create collaborative systems that are apt to manipulate the collaborative process motivating or even enforcing users to adopt a particular coupling pattern.

**Workspace Awareness.** Another essential advantage of LHRDs is that they are apt to provide extensive support for workspace awareness - the ability to *"maintain awareness of others' locations, activities, and intentions relative to the task and space"* (Gutwin and Greenberg, 1996). That allows all team members to overview the entire process of level prototyping, see the produced results immediately, and intervene rapidly if some problems occur. On the other hand, workspace awareness can become a source of recurrent distractions (Sigitov et al., 2016), thus affecting the experience and efficiency of designers negatively.

# 3 LHRD GROUPWARE FOR 2D LEVEL PROTOTYPING

The software infrastructure we developed for collaborative 2D level prototyping on LHRDs consists of four main components (see Figure 1): server, mobile client, display client, and level editor. Mobile clients can run on a mobile device, laptop, or a conventional desktop computer. It provides an interactive interface to users and allows them to create visual artifacts in the form of map tiles. Display clients take commands and messages from the server and pass them to the level editor. The level editor application encapsulates the display client component for communication purposes. The server is a connecting link between clients; therefore, clients communicate only with the server or through the server, and no client does know anything about other clients.

The system uses the following protocol to register clients on the server. On each new connection, the server puts the client into the waiting pool first. Next, it asks the client to identify itself; after that, the client responses with its type and name. Depending on the type of the client, the server chooses a communication protocol and allocate appropriate data structures for the client. Subsequently, the server responses and conveys a session-id to the client. That means that the server registered the client. Finally, the client can send data.

## 3.1 Mobile Client

The mobile client (Figure 1) represents an interaction interface between the user and the system. Using a device with the mobile client application running the user can log in on the server, move her pointer on display, create map tiles, and put or delete tiles on the map. Additionally, the mobile client application performs data transformation of the user input. The data transformation is necessary since the application can run on different devices, e.g., tablet-PC or laptop.

The mobile client application consists of three panels. The user can switch between *Controller*, *Craft*, and *Settings*. The Settings panel allows the user to adjust her pointer's color and speed on the LHRD. The *Craft* panel allows the user to create new tiles. The panel contains the palette with different colors, slider for brush size adjustment, canvas to draw, a text field to name the tile, and two buttons save and reset. The *Controller* panel contains the menu bar, tiles bar, interaction field, recycle bin, and drop area. The menu bar allows the user to hide and show the *Settings* and *Craft* panels, quit the application, or delete a tile on a map. The tiles bar contains all the tiles created by the user or her co-workers. The user can drag a tile from the tiles bar into the recycle bin to delete it, or into the drop area to put the tile onto the map.

In our system, we implemented the discrete coarse-and-precise pointer interaction technique similar to Nancel et al. (2013). The precise pointer has the form and the size of a single tile, so it marks the area on the map a tile will be put in. The coarse pointer, on the other hand, has the size of a display unit, thus providing a possibility for fast navigation between remote areas on display. The precise pointer always remains within the coarse pointer, thus moving the coarse pointer will also move the precise pointer.

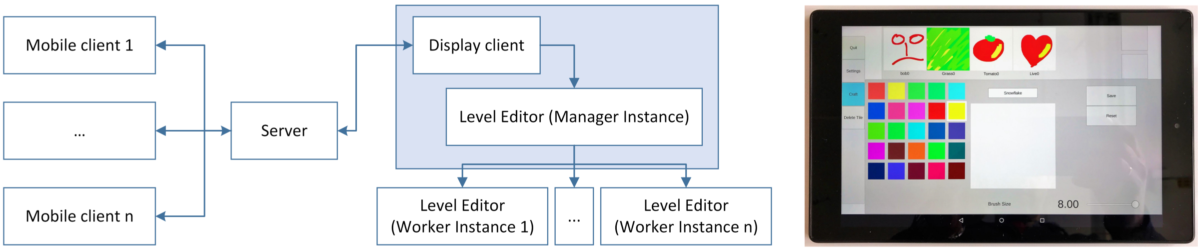


Figure 1: (left) System overview; (right) the mobile client application running on the tablet-PC.

The interaction field in the mobile client application allows controlling of both pointers. The user can move the precise pointer by making the swipe gesture with one finger, while with two fingers, the user can move the coarse pointer.

### 3.2 Server

The server application is responsible for multiple tasks. It logs in a database every piece of information that was received or sent by it, thus allowing for an in-depth analysis of client interactions. It also backups the current state of the system and distributes it to the newly connected clients, thus ensuring the integrity and reliability of the system.

The server also manages communication between clients. Every time the server receives a data package, it decides first what clients are affected by this new information, for instance, if the server receives a tile then all clients in the environment have to be updated. If, however, a mobile client reports on movement in the interaction area, then only the display clients receive the notification. Additionally, it can perform data transformation, means transform data from a client into an appropriate form for other clients. For instance, the mobile client application can report on one-finger swipe gesture passing a relative delta since the last frame. In that case, the server has to accumulate the values and command the display client to move the precise pointer of the user one tile left if the accumulated value exceeded a given threshold. Thus, the continuous values from the mobile client become a discrete value that can be understood by the display client.

### 3.3 Level Editor and Display Client

The level editor application was implemented using a Unity plug-in for LHRDs (Sigitov et al., 2015). The level editor contains a simple 2D tilemap which is shown on display and can be edited by users using mobile clients. To configure the editor, the developer must provide the following values: the size of tiles (which is also the size of the precise pointer); the size of the display units (which is also the size of the coarse pointer); width and height of the map.

Using the Unity plug-in for LHRDs, a set of virtual cameras that mimic the physical configuration of the display is defined. Each virtual camera becomes assigned to an individual display unit. The level editor application consists therefore of $n$ instances with $n$ equals the number of display units. All instances are synchronized using mechanisms provided by the plug-in.

One instance of the level editor application (called manager) encapsulates the display client. The display client is responsible for receiving commands from the server and triggering the appropriate command in the level editor (e.g., show/hide coarse/fine pointer, place/delete tile). The commands are triggered only on the manager. It, in turn, performs the desired action, subsequently changing the internal state of the virtual world, and finally distributes the new internal state, among other instances.



## 4 USER STUDY

With the study, we aimed to assess users' attitude towards LHRD-based systems for co-located collaboration in the context of creative tasks, and investigate the collaboration process in the context of creative tasks. We also wanted to identify how a user interface that forces users to adopt a specific role within the team will affect the collaboration process, and get feedback on the developed groupware for 2D level prototyping to identify potential improvements. We utilized the system described in section 3 and let participant dyads build 2D game levels for 30 minutes. Apart from the time constraint, we did not set any other constraints.

### 4.1 Study Design

We used a between-groups study design. The independent variable was *Condition* with two levels, namely *Equal Roles* and *Different Roles*. In the *Equal Roles* condition, participants were provided with identical interfaces. Thus both group members could perform the same set of manipulations. In that case, the participants could ignore the concept of user roles entirely, or they could dynamically (re-)assign roles.

In the *Different Roles* condition, the participants were provided with two different interfaces. One interface allowed only for the creation of visual assets, while the other interface allowed for the placement of visual assets only. Therefore, the participants had either undertake the role of a 2D artist (creation of visual assets) or a level designer (placement of visual assets). We used the same mobile client application as in the *Equal Roles* condition. For 2D artists, however, we deactivated modules that are responsible for interaction with the LHRD, while for level designers we disabled the *Craft* panel.

During the study, we gathered qualitative data that included surveys, field notes, and video recordings. In total, we gathered 368 minutes of video/audio data. Moreover, we obtained quantitative data that encompassed the participants' position, pointer positions, and task-related system events.

## 4.2 Apparatus

We conducted the study on a large, curved tiled-display (see Figure 2) comprising 35 displays (henceforth display units) ordered through a seven (column) by five (row) grid. Each column has a relative angle difference of 10 degrees along the Y-axis to adjacent columns, as such, creating a slight curvature. The display units were 46" panels with a 1080p resolution. The application for the display was implemented using the Unity game development platform with a special plug-in for large displays (Sigitov et al., 2015).

We used an array of seven infrared cameras to track users' heads through head-worn helmets within an area of around 20 square meters directly in front of the display. For interaction purposes, we utilized two identical Amazon Fire HD 10 tablets. The tablets ran an application to control the pointer position on the display and create visual assets. Use of the tablets as interaction devices allowed us to untether participants, thus foster physical navigation, and to extend operative display's real estate by a highest and the lowest row. In the case of touch-capable large displays, these areas would be hard or even impossible to reach.

## 4.3 Procedure

A supervisor guided participants through the entire study. First, the supervisor asked the participants to

Figure 2: Large, curved tiled-display used for the study. The display shows a 2D level prototype created by a group of participants.

fill in a consent form and a demographics questionnaire. Next, the supervisor explained the task, the procedure of the study, what equipment the participants will wear, and how and what data the system will gather. In the case of *Different Roles* condition, the supervisor also asked the participants to decide who will undertake which role. If participants could not decide, the roles were assigned randomly. Afterward, the supervisor demonstrated how the groupware works and invited the participants to try it out. The participants had as much time as they needed to get to know with the system. Finally, the supervisor equipped the participants with helmets which were used for position tracking and let them build a 2D game level for 30 minutes. During the study, the supervisor observed the process and made field notes. After the time expired, the participants filled in the questionnaires and supervisor conducted a short oral interview.

## 4.4 Participants

We performed the study with 12 groups of two participants each. Six groups must accomplish the task under *Equal Roles* condition while the other six groups accomplished the task under *Different Roles* condition. The participants of the *Equal Roles* condition were aged between 21 and 41 years (M = 27.58; SD = 6.05). The participants of the *Different Roles* condition were aged between 20 and 35 years (M = 24.67; SD = 4.23). All participants had a normal or corrected-to-normal vision. There were four female and eight male participants in both conditions. Each participant took part only once in the study. All participants had an academic background (students or research associates). Each participant received 10 Euros for taking part in the study.

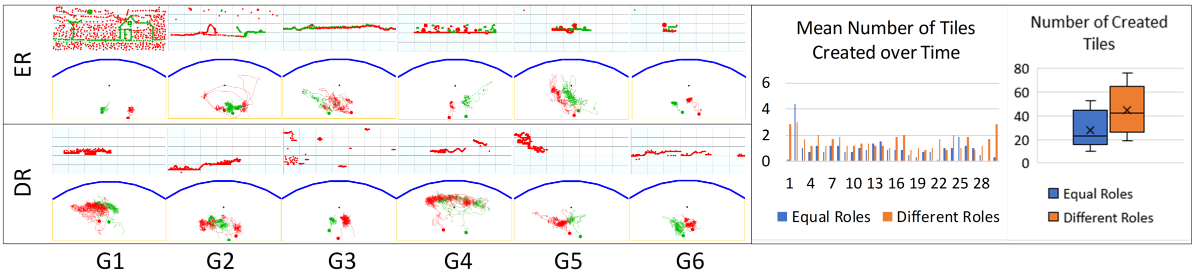


Figure 3: (left) Visualization of display usage [front view] and user movements [top view] in Equal Roles [ER] and Different Roles [DR] condition. Gray grid represents the LHRD from the front. The green and red dots on the grid depict the position of the tiles. The blue curved line represents the LHRD from the top. The yellow lines outline the tracking area in front of the LHRD. The green and red lines inside the tracking area depict the movements of the users during the study. (right) Number of created tiles in different conditions.

# 5 RESULTS AND DISCUSSION

In this section, we present and discuss the results acquired through the analysis of gathered qualitative and quantitative data. We used questionnaires to evaluate users' attitude towards the system and to receive feedback on developed groupware. The majority of questions provided a 7-point Likert scale for the answer (from 1 = bad / strongly disagree to 7 = good / strongly agree). There were also three questions with free text answers where the participants could explain what groupware functionality they missed, what interaction device they would prefer to use instead of the provided one, and also leave some free comments.

To capture and analyze the collaboration process and effects of the different interfaces on the process, we used video recording, observations, field notes, oral interviews, and system logs. There was also a set of 7-point Likert scale questions to acquire the participants' subjective perception towards the collaboration process. Table 1 summarizes the questionnaire results. In the following subsections, we first present results regarding the system and groupware. Next, we go over to the observed design process and consider results regarding physical navigation, territoriality, collaborative coupling, and workspace awareness. We provide the results separately for the *Equal Roles (ER)* condition and *Different Roles (DR)* condition.

## 5.1 System Evaluation

**Overall System and Groupware.** The participants found the system rather ***easy to use***. They acknowledged that the system is ***easy to learn*** and that ***one can quickly become skillful with it***.

Most participants stated that ***it was fun to use the system***; that the ***system makes the work more interesting***; and that they found that the ***system is suitable for the provided task***.

The participants, however, stated that they were only ***partially satisfied with the system*** and that it only ***partially worked the way they wanted***. The oral interviews revealed that it was due to some missing functionality the participants would prefer to have in the system. The results also revealed that the participants of the *Different Roles* condition felt ***more comfortable working with the system***, and that the participants of the *Equal Roles* condition would rather ***prefer to have a sitting accommodation*** while the participants of the *Different Roles* condition could rather spare it.

The results suggest the provided groupware as a solid basis for future development. It can be extended to provide more sophisticated tools for users in terms of drawing and asset placement. So, for instance, the participants wished to replace the field with the predefined colors with the RGB-wheel, to allow cloning and editing of created tiles, the possibility to set multiple at once, and a *eye-free technique* for setting tiles. Additionally, the groupware can be modified to support other creative tasks, like interior design. It is also a good idea to provide sitting accommodation for longer sessions. Overall, the participants expressed a positive attitude towards the system and the system suitability for the design task.

**Large, High-resolution Display.** The participants stated that the ***display is suitable for the provided task*** and for the ***co-located collaboration***. Yet, the participants of the *Equal Roles* condition ***were not sure if a common desktop display would be more suitable for the task***. However, the participants of *Different Roles* condition rather disagreed that a common display would be a better choice.

The participants felt in general ***comfortable working with the display***. Yet, some participants ***felt physical discomfort*** during the task. Additionally, 11 out of total 24 participants found the ***display rather too***

Table 1: Questionnaire results: the participants assessed the system using a 7-point Likert scale with 1 = bad / strongly disagree to 7 = good / strongly agree.

| | Equal Roles | | Different Roles | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| **Overall system and groupware** | | | | |
| easy to use | 5.33 | 1.30 | 5.66 | 1.37 |
| easy to learn | 6.41 | 0.67 | 6.67 | 0.65 |
| I quickly become skillful with the system | 5.58 | 1.31 | 5.83 | 1.19 |
| The system is fun to use | 5.58 | 0.99 | 5.58 | 1.73 |
| The system makes the work more interesting | 5.58 | 1.24 | 6.08 | 1.24 |
| The system is suitable for the provided task | 5.25 | 1.13 | 6.08 | 1.08 |
| I am satisfied with the system | 4.08 | 0.99 | 4.83 | 1.33 |
| I felt comfortable working with the system | 5.41 | 1.08 | 6.00 | 0.60 |
| I would prefer to have a sitting accommodation | 5.25 | 1.65 | 3.16 | 1.75 |
| **Large, high-resolution display** | | | | |
| The display is suitable for the provided task | 5.83 | 0.83 | 5.75 | 1.14 |
| The display is suitable for co-located collaboration | 6.08 | 0.51 | 6.25 | 0.62 |
| A common desktop display would be more suitable | 3.75 | 1.28 | 2.75 | 1.42 |
| I felt comfortable working with the display | 5.41 | 1.08 | 6.00 | 0.60 |
| I felt physical discomfort while working with the display | 3.25 | 2.05 | 2.42 | 1.16 |
| I think the display is too large for the task | 3.83 | 1.94 | 3.08 | 2.02 |
| **Interaction device** | | | | |
| The interaction device is suitable for the task | 5.4 | 1.07 | 5.08 | 1.38 |
| It was easy to master the interaction device | 6.25 | 0.75 | 5.50 | 1.17 |
| I felt comfortable working with the interaction device | 4.83 | 1.19 | 5.33 | 1.56 |
| I felt physical discomfort while working with the interaction device | 3.66 | 1.72 | 3.58 | 1.83 |
| **Perception of collaboration** | | | | |
| I and my partner worked entirely cooperative | 4.33 | 1.23 | 5.67 | 1.07 |
| It was fun to work collaboratively | 6.00 | 1.13 | 6.58 | 0.67 |
| My partner distracted me during the work | 1.75 | 0.62 | 1.33 | 0.65 |

***large for the task***.

Overall, the results showed that users consider LHRDs as an acceptable visual interface for co-located collaborative work and that they could imagine working with such devices in the future. The participants were satisfied with the display, its size, and its curvature. Although some participants felt physical discomfort while working with the display, we could detect during the oral interviews that it was due to frequent switches from the tablet display to the large display and vice versa. This problem is solvable through an eye-free technique for asset placement. Generally, we can conclude that, if a system provides a secondary display in addition to a LHRD, then designers must ensure an interaction process that keeps the number of switches between two displays as low as possible.

During the oral interviews, the participants also explained that in the given 30 minutes, it was practically impossible to utilize the entire display real estate. Thus the display could be smaller, in their opinion. If, however, they would have enough time, then the size would be acceptable. We also asked the participants if it would be better to have a flat display instead of curved. All participants stated that it would be worse.

**Interaction Device.** Most participants agreed that the provided ***mobile device is suitable for the task*** and that it is ***easy to master***. Most participants ***felt rather comfortable working with the mobile device***. Yet, ***some participants felt physical discomfort***. Fifteen out of total 24 participants ***were satisfied with the provided mobile device*** and would stick to it; 5 out 24 participants would prefer to work with a ***more lightweight tablet device and/or have a stylus*** for better drawing; 4 out 24 participants would prefer to have ***another interaction device/interface***, e.g. laser pointer, game controller, or touch capable large display.

The results showed that the majority of users were satisfied with the tablet PC as an interaction device. Better acceptance could is achievable through the utilization of more lightweight and more qualitative devices with support for pen input. In contrast to large displays with direct touch input, mobile devices provide better support for LHRDs in terms of reachability of remote display areas and objects. Moreover, they allow for interaction from a distance and mitigate occlusion situations. Since user acceptance is high, we would recommend designing interaction around this kind of devices and as mentioned above, set focus on eye-free interaction techniques.

### 5.2 Group Behavior

**Physical Navigation.** During the experiment, participants did not frequently change their location in front of the display (see Figure 3). Most of the time, the participants positioned themselves in an overview position, and physical navigation was reduced to head and body rotations.

We ascribe the observed behavior to two factors: the curvature of display and the size of tiles. Although we made tiles relatively small (45px x 45px), the participants could work well with that size from a distance. Additionally, the curvature of the display allowed the participants to work comfortably on practically all display regions staying in the middle of the working area. Thus, the participants did not depend on location changes and could switch between working display regions display by merely rotating their heads or bodies.

Overall, the impact of physical navigation was marginal in both conditions.

**Display Usage.** Most participants preferred to work in a comfortable display region. We could see, however, that they utilized other display regions as well. The observed behavior is not unexpected. Since the participants had only 30 minutes to complete the task, we did not expect that they would be able to build a level which takes the entire display. We asked them, however, to work as if they would have enough time to do so. We did not prescribe where the participants should start and in what direction the level should expand. As Figure 3 depicts, most groups (groups 2,3,4,5,6 in the *Equal Roles* condition, and groups 1, 4, 6 in the *Different Roles* condition) worked predominantly in the middle row of the display. Two groups (group 1 in the *Equal Roles* condition and group 3 in the *Different Roles* condition) tried to utilize the entire display. One group started in the top left corner of the display and the other group in the bottom left corner.

**Territoriality.** The *Different Roles* condition did not allow for territorial behavior on the shared display. In the *Equal Roles* condition, however, we could observe distinctly territorial behavior in the early stages of the experiment. Four out of six groups decided to split the task by area after they have established a common ground and agreed on what kind of level they want to build. The participants divided then the display into the left and right side and started to work loosely from the outer display edges to the center. Figure 3 depicts this behavior that was exposed by groups 2,3,4, and 5 during the *Equal Roles* condition. After the participants met, the territorial behavior diminished, and the participants split the task mostly by a sub-task (e.g., one participant drew and placed coins, while the other drew and placed plants).

We could not see any necessity for supporting territoriality or providing special tools for territory management. Since the participants perceived the collaboration as tight, they did not feel threatened or disturbed by the actions of the partner. One possible improvement could be an overview territory on the shared display to show all created tiles at once. That will ensure a better workspace awareness and create a new ground for more tightly coupled work.

**Creation of Assets.** Figure 3 depicts the finding regarding tiles creation. The analysis of the system logs showed that the creation of assets took place over the entire session. All groups in both conditions demonstrated this behavior. The supervisor who made field notes also detected the behavior. We ascribe the behavior to the fact that the participants repeatedly received new ideas during the design process, thus returning to the *draw tile* sub-task.

We could also detect that the groups in the *Different Roles* condition created, on average, more tiles in comparison to the groups in the *Equal Roles* condition. We assume that the distribution of roles created a feeling of responsibility for the assigned task, thus leading to more focused work which, in turn, results in better productivity. However, the statistical analysis using independent-samples t-test revealed that the difference was insignificant.

**Perception of Collaboration.** The participants ***felt working rather cooperatively*** and agreed that it was ***fun to work collaboratively***. They also ***did not feel distracted by the partner***. Only 3 out of 24 participants stated that they would rather prefer to work alone and that they would perform better if working alone. All three participants belonged to the *Equal Roles* condition.

**Collaborative Coupling.** To analyze the collaborative coupling behavior, we analyzed the video recordings multiple times. We first, identified periods of loosely and tightly coupled work, measured the length of those periods, and calculated the overall time of loosely and tightly coupled work for each group. Figure 4 shows the results of the analysis.

The visualization exposed noticeable difference between the *Equal Roles* and *Different Roles* conditions. In the *Equal Roles* condition the participants


Figure 4: Level design process for different conditions: (left) periods of loosely and tightly coupled work; (center) total time for loosely and tightly coupled work; (top right) state diagram for the Equal Roles condition; (bottom right) state diagram for the Different Roles condition

seemed to work more in a loosely coupled manner. Thus, we conducted an independent-samples t-test to compare the time the participants spent working loosely coupled in different conditions. The analysis revealed a ***significant difference*** in the scores for the *Equal Roles* condition (*Mean* = 1331.21, *SD* = 290.17) and the *Different Roles* condition (*Mean* = 908.48, *SD* = 174.75); $t(10) = -3.06, p = 0.012$. The detected significant difference indicates that utilized interfaces can have a great effect on how users approach a common task and on how they shape their collaboration. Especially in teams that contain users who do not know each other well (or not at all) interfaces that force tightly-coupled work might be of advantage resulting in a more coordinated workflow and more consistent results.

Next, we detected what sub-tasks the participants approached during the identified periods. Based on the gained information, we created state diagrams that describe the collaboration processes for the *Equal Roles* and *Different Roles* conditions. Figure 4 depicts the state diagrams. The results show that the participants of the *Equal Roles* condition shaped the collaboration process differently in comparison to the *Different Roles* condition.

In the *Equal Roles* condition, the participants started with establishment of a *Common Ground*. They discussed what kind of level they want to build, what tiles are necessary, who will create what tiles, where the ground will be, and where they should start to place tiles. Next, they moved on to the *Draw a Tile* state working loosely-coupled. After the participants created first tiles, they could move on to the states *Place a Tile* or *Ponder Next Steps*. In both states, the participants worked in a loosely coupled manner. They could also switch to the tightly coupled step *Coordinate Work*, for instance, to share new ideas, ask for advice, or propose new tiles.

In the *Different Roles* condition, the participants started similarly with a discussion over general parameters. Subsequently, they moved on to the state where 2D artist was drawing, and the level designer was waiting for the tiles. After they created first tiles, the participants would either switch over to a state where the level designer was placing the tiles, and the 2D artist was waiting for new requests or to the state where the level designer was building, and 2D artist was continuing to draw more tiles. Additionally, participants could also switch over to the coordination state to discuss what steps to take next. Overall, the participants worked more coordinated and more tightly in the *Different Roles* condition. Notably, the participants playing the 2D artist role were involved in the work of the level designer more deeply. It did not always work the other way around. Some 2D artist produced many assets without being asked for them. That sometimes required additional coordination, since the level designer could not decipher the meaning of tiles.

We also asked the participants of the *Different Roles* condition if the idea of roles distribution does make sense. Most participants (10 out of 12) found the idea sensible on the basis that each of them could focus on his/her sub-task and therefore provide more qualitative results. They also stated that they did not miss the functionality the co-participant had.

Groupware developers can utilize the concept of *User Roles* to direct the collaboration process during creative work and to push it towards more tightly work. The roles must be well balanced to ensure that all team members will have enough work for the entire session. Otherwise, users might become a feeling of being expendable, and the work process might become less satisfying. We observed such a situation by one group where the participant who was playing the 2D artist role experienced periods of idleness.

**Workspace Awareness.** Finally, we also looked for evidence of workspace awareness during the study. Two sources could potentially increase workspace awareness of the participants: the large display and the mobile devices. The mobile devices were synchronized, which means that if one participant created a tile, it would appear in the library panel on the tablet of the co-participant. Additionally, the panel will automatically scroll down, so the tile becomes visible.

The supervisor could multiple times observe that the participants laughed or smiled when a new tile, created by the co-participant, appeared in their library panel. In some cases, however, we could detect that this also leads to interferences. For instance, in the *Different Roles* condition, one 2D artist always waited until the level designer was done with tile placement before he submitted a new tile. Otherwise, due to the auto-scroll function, the level designer must navigate in the tiles library to the tile he was currently using.

During the oral interviews, We also asked the participants if they occasionally observed what the partner was doing and if that affected them by any means. All participants answered in affirmative. Most participants (22 out of 24) stated that they were ***inspired*** by what the partner was doing and received new ideas. Two participants also stated that they observed the partner actions to **avoid interferences**. One participant stated that he was in no way affected by what the partner was doing.

## 6 CONCLUSION

In this paper, we presented groupware for co-located collaborative 2D level design on LHRDs using tablet PCs for interaction. The evaluation results revealed a positive users attitude and high level of acceptance towards the system. The results also identified the directions of future improvements, like more sophisticated tiles editor, more lightweight and more qualitative tablet-PCs, as well as eye-free techniques for asset placement. The implementation of the presented groupware allows an arbitrary number of users. Moreover, it can be easily modified to support different design tasks.

Furthermore, we presented a study comparing users behavior while working with and without specific roles distribution. The study showed that whether users have to work with identical interfaces or with different interfaces which force them to undertake a specific role significantly affects the collaboration process. Providing interfaces that enforce the distribution of roles can help to shape a more tightly-coupled and coordinated workflow as well as achieve more consistent results. Moreover, the majority did not perceive such limitations as awkward and welcomed the configuration. When designing groupware for co-located creative tasks on LHRDs, this may create new opportunities. Groupware developers can exploit this knowledge to create systems which will be able to affect the collaboration process.

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