Chapter 2
Tabletop 3D Object Manipulation with Touch and Tangibles

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Abstract Tabletop environments are ideal for collaborative activities that involve moving and arranging objects. However, manipulating 3D virtual objects through the 2D interface is challenging because users' 2D actions must be translated into 3D actions. We explore the use of touch and tangibles to aid collaboration and 3D object manipulation. Our user study shows that using touch and tangible interaction together has advantages 3D object manipulation. While most users preferred touch due to its familiarity, the tangibles were favored for some tasks.

2.1 Introduction

Three dimensional object manipulation is a common task, which involves translating, rotating or scaling a selected object [11]. These tasks are difficult with 2D input devices because objects can be manipulated on nine dimensions, three dimensions each for translation, rotation and scale [17] but the 2D input device maps naturally to only two dimensions. Examples of tasks that involve 3D object manipulation include laying out animated film sets, furnishing virtual rooms in architectural concept plans and playing games. These tasks are often undertaken by small collaborative groups, thus when using a computer a large display is preferable.

Multi-touch interaction is the current default for large display interaction. An under-explored alternative is Tangible User Interfaces (TUIs). TUIs provide real physical objects with which the user can manipulate virtual objects. They provide a more direct method of interaction than mouse, pen or touch. A number of projects have explored using tangibles for Lego-style construction. However, to the best of

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Fig. 2.1 Participants interacting with virtual Jenga [19]

our knowledge, there is no work that uses tangibles, with or without multi-touch, to directly manipulate generic objects in a 3D scene (Fig. 2.1).

Collaboration is a key design goal behind many TUI systems [22]; research has shown they are beneficial for collaboration e.g. Jordà et al. [12]. Properties of TUIs that support collaboration include: lowering the barrier to interaction due to the familiarity with real-world interactions [22]; they are more welcoming than mouse driven interfaces due to support for parallel interaction; and they physically embody facilitation, as they can be designed to guide collaboration between participants, for instance, a tangible can be used to give a particular participant control, or encourage equal participation [22]. While we often think of collaboration as working together to build something, competitive games are also a collaborative activity [20]. Players collaboratively agree on the rules of play and on what constitutes a win. They then challenge each other in a collaborative-competitive setting.

To explore combining touch and tangibles for interacting with a 3D world through a tabletop we created virtual Jenga [19], a turn based game where players are situated around a stack of rectangular blocks. The players take turns pulling blocks from the stack and placing them on the top of the stack. The first person to knock the stack over loses. Jenga was our selected context as it allowed us to focus specifically on selection and manipulation of 3D objects. We developed a set of 2D touch gestures and tangibles through an exploratory Wizard of Oz user study. The most promising gesture and tangible interactions were then implemented and iteratively refined in our virtual Jenga game on a Microsoft Pixel Sense tabletop. After usability testing and further refinement, the final evaluation was a Jenga tournament.

This naturalistic evaluation provides an insight into how users can quickly learn to manipulate 3D objects using a combination of touch and tangibles. A video of the project is available online (https://vimeo.com/diprose/tangibles).

2.2 Related Work

Three dimensional object selection and manipulation are common tasks performed in 3D environments. The object manipulation involves choosing the desired object to manipulate (selection) and then translating, rotating or scaling it [11]. Despite this being a common task, it is challenging because there is no natural mapping between the 2D inputs commonly used for computer interaction, and 3D movement [17].

There are four general methods for mapping 2D input into 3D movement [23]. First, on-screen widgets are used to map each axis of movement onto separate controls; the user can then break 3D movement into combinations of 1D or 2D movements. Second, objects can be moved relative to the viewing plane; either parallel or orthogonal. Third, objects can be moved relative to structures in the scene, for example, Oh and Stuerzlinger [17] developed an algorithm that allows objects to be dragged along the surface closest to the viewer but occluded by the object being dragged. Fourth, using heuristics based on the direction of the input device movement. These projects have used mouse input, predating the commercialization of multi-touch input.

Traditionally manipulation of 3D spaces was via a mouse [8]. A mouse provides single point interaction, with all its obvious drawbacks for 3D manipulation. This has been extended to pen interaction, e.g. McCord et al. [13], however, this is also single point interaction. The advent of multi-touch input displays has seen an extension of this work to provide touch interaction to the 3D space, see Jankowski and Hachet [11], for a recent literature survey. However, there is still not a generally accepted set of touch gestures for the many and varied tasks that can be undertaken in virtual 3D spaces. Various other input methods have been proposed including immersive environments, brain-computer interaction, and puppetry using depth-sensing cameras. Tangibles on a tabletop match our real-world experience more closely than these alternatives

Tangible User Interfaces (TUIs) are an alternative to mouse, pen or touch. TUIs provide a real physical object for the user to manipulate a virtual object with [25], which gives users a more direct method of interacting with a computer [24].

A number of TUI systems have been created for constructing geometric LEGO-like models on a computer using physical blocks, e.g. [26]; Aish et al. [1]. Altering the construction of the physical blocks updates the model displayed on the screen. Cuendet et al. [4] had participants manipulate a 3D world and then select particular block edges. Other work has explored how tangibles can be stacked [2] or sensed in mid-air Held et al. [9]. However, both approaches have unsolved problems. Rearranging stacking tangibles is fiddly and constrains the user to the real world physics of the tangibles. Held et al. [9] used tangibles and a depth sensing camera to move objects in a scene, they report that users could, with some practice, create a simple story, but there are numerous limitations to the current implementation. Working on the tabletop provides a more natural working space with higher accuracy input.

To the best of our knowledge, there is no work that uses tangibles to directly manipulate generic objects in a 3D scene or work that combines multi-touch and tangibles. The closest work is from Bock et al. [3], who developed a set of tangible widgets for playing 2D multiplayer tablet games. They compared the usability of the tangibles to multi-touch interaction and found that users preferred the tangibles over multi-touch. A possible reason for this is that the tangibles allowed the users to focus on the other player rather than on manipulating their own character. This suggests that TUIs may also have benefits for 3D object manipulation.

2.3 Our Approach

In this project we investigate how multi-touch and tangibles together can be used to manipulate objects in a 3D tabletop environment. Our specific research questions are;

RQ1. How can multi-touch and tangibles be used to manipulate 3D virtual objects in a collaborative tabletop environment?

RQ2. Which interaction method is more suitable for each of the sub-tasks involved in 3D object manipulation?

RQ3. Is tangible, multi-touch interaction on a tabletop suitable for collaborative-competitive games?

To provide a context for this inquiry we adopted the block-stacking game Jenga [19]. To be successful playing the game very accurate manipulation of the blocks is required. While Jenga uses regular blocks, their movement and docking is not constrained. Therefore, we posit that interactions that are successful in Jenga will translate well to other 3D object manipulation tasks.

In order to do this we: designed a set of multi-touch gestures and tangibles suited to the task (Sect. 2.4); implemented an appropriate environment for the multi-touch and tangible interaction and verify its usability (Sect. 2.5); carry out a realistic user evaluation of the environment (Sect. 2.6).

2.4 Observational Study

A Wizard of Oz [5, 6] observational study was conducted to understand what gestures and tangibles people find intuitive when manipulating 3D objects through a 2D interface. There were seven participants in the study, four male, and three female, their ages ranged from 22 to 35, all were experienced touch device users.

2.4.1 Method

The study used a real stack of Jenga [19] blocks placed underneath a transparent acrylic sheet (Fig. 2.2). The acrylic sheet acted as a 2D screen, on top of which users could make gestures with their fingers, hands and tangibles. The users explained what they expected to happen as they performed actions, the real Jenga blocks were manipulated by the facilitator to match the participant's verbal instructions. A number of tangibles were provided, including a stack of Jenga blocks, a single Jenga block, and two unspecified objects that the users could assign meaning and actions to—for example a user could say 'this is a magnet and a block sticks to it when I place it on the block'.

Data was collected with pre and post-task questionnaires, a second facilitator observed each participant and multiple cameras were used to record participants' gestures.

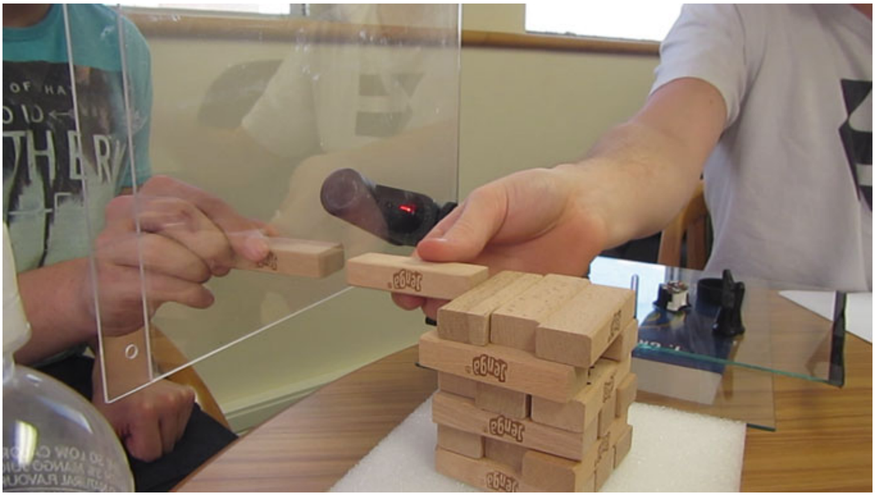

Fig. 2.2 Wizard of Oz interaction example with a user on the *left* simulating a tangible interaction and a facilitator on the right following the user's instruction to move a block

2.4.2 Tasks

Participants performed three sets of tasks. To familiarize the participants with the objects the first set of tasks was completed on the physical blocks. Task sets two and three, touch gestures and tangibles respectively, were performed on the acrylic sheet. Task sets two and three were given to participants in different orders to reduce order effect bias.

Each set of tasks consisted of sub-tasks split into sections:

- Change the camera view of the stack (4 variations of top and side view) (task sets 2 and 3 only)
- Single block manipulation
  - Rotate block −4 variants of direction and degrees x2 (top and side view).
  - Move block on the horizontal and vertical plane −8 variations x2 (top and side view).
  - Remove block from the stack −3 variations, side, and center blocks x2 (top and side view).
- Complete task
  - Move an edge block to the top of the stack (x2 starting from top or side view)
  - Move a center block to the top of the stack

In total, each participant completed 104 tasks.

2.4.3 Results

The results showed common themes for a number of block manipulation tasks. To translate blocks left/right/up/down participants almost always used a single finger drag, and to rotate blocks participants, by and large, used the two-finger rotate gesture. The most commonly used tangible for these tasks was the block tangible. It was placed on the virtual block and moved and rotated to perform these actions.

The most difficult task in real Jenga is to remove a block from the center of a row because of the accuracy required not to move the surrounding blocks. Working through the acrylic sheet, it was clear that the only logical way to remove a center block from the stack is to move a block orthogonally to the screen. However, there was little consensus among participants for moving blocks orthogonally; many different solutions were given, participants often used previously used gestures or didn't know how they would perform this action. Some suggested, so as to not overload gestures, the pinch touch gesture be used for this action. For the tangible equivalent, a 'screwdriver' tangible that is rotated to move the selected block orthogonally suggested by one of the participants seemed to have the most promise.

Our study design constrained movement of the camera view to either top or side positioning of the acrylic sheet. As we will discuss below much more flexible camera positions are easily achieved in the virtual environment. With the constraints we imposed, the most common touch gesture suggestion was the addition of slider-bar widgets. For the tangible manipulation, users suggested placing the tangible Jenga stack provided at the orientation required.

2.5 Virtual Jenga

To realize the results of the observational study, we implemented a multiplayer Jenga [19] block stacking game for a large tabletop display. To compare multi-touch interactions with tangible interactions, we designed and implemented two interaction schemes in the Jenga game: multi-touch based interaction and tangible based interaction. Each interaction scheme has a method for manipulating the camera view, selecting and deselecting blocks, moving and rotating blocks, and translating blocks orthogonally to the camera view.

2.5.1 Implementation

The Jenga game was implemented on a Microsoft PixelSense table, specifically the Samsung SUR40 [21]. XNA Game Studio 4.0 [14] was used to develop the game, as it integrates easily with the Microsoft Surface 2.0 SDK [15]. The Henge3D [10] physics engine was used with XNA Game Studio to provide the physics capabilities of the game.

The touch and tangibles were recognized with the Microsoft Surface 2.0 SDK core layer [16] which processes and recognizes three types of objects in contact with the screen: fingers, blobs, and byte tags (Fig. 2.3).

To track the tangibles we initially used byte tags, these worked fine when the position and orientation weren't needed (e.g. for the stack tangible), however, they gave unstable readings for the position and orientation of objects. To identify and track the position and orientation of the tangibles more accurately, we used blob pairs [27], which consist of a small blob and a large blob. By drawing a line between the centers of these two blobs, the orientation of the tangible is able to be

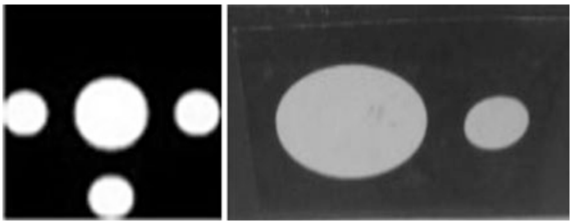

Fig. 2.3 Byte tag, blob pair used to track a tangible's position and orientation

determined. Blob pairs are uniquely identified by the width of the two blobs and the distance between the blobs.

User's interactions with the system are logged into a CSV file for later analysis. Each row contains the player currently interacting with the system (specified with a button on screen), the type of interaction and the time that this occurred. This data together with video recordings allow us to analyze the users' interactions.

2.5.2 Touch and Tangible Interaction

The touch and tangible gestures used in our virtual Jenga game were developed through a process of iterative refinement. This began by using the results of the Wizard of OZ observational study to create the first prototype. As we developed the system more alternatives were investigated and informally tested. The prototype was then evaluated with a usability test; six participants undertook this study individually. We then refined the interaction based on the results of the usability test before evaluating the final prototype with a Jenga tournament that is reported in Sect. 2.6. This section describes the design decisions behind the interaction schemes for touch and tangible interaction and how they evolved during development and usability testing.

2.5.2.1 Camera View Manipulation

Touch

Our observational study camera view was constrained to two views, top and side. However, most 3D development kits include infinitely flexible camera manipulation. Initially, we explored using touch interaction to manipulate a free-flying camera, this allowed users to move forwards and backward as well as move the camera up, down, left and right. We decided against this design because having to manipulate too many camera axes, distracted users.

The next iteration constrained the camera by fixing the focal point to the Jenga tower. Using slider-bars, as suggested in the observational study, the camera orbits around the Jenga tower. From the user's perspective, the Jenga Tower appeared to rotate as the sliders were manipulated. Informal testing suggested that the slider bars were a step in the right direction but still caused a disconnect between the users and the game. Users would look away from the stack, to use the slider bars and then look back to the stack again. This tended to take the user out of the game mentally. In addition, the slider bars introduced unnecessary widgets thus increasing interface complexity.

The final iteration combined features of the previous two interactions. Focus is fixed on the Jenga stack and the camera is manipulated with a finger drag (Fig. 2.4a): dragging your finger left or right rotates the camera around the Jenga stack, whilst dragging your finger up or down rotates the cameras vertically around

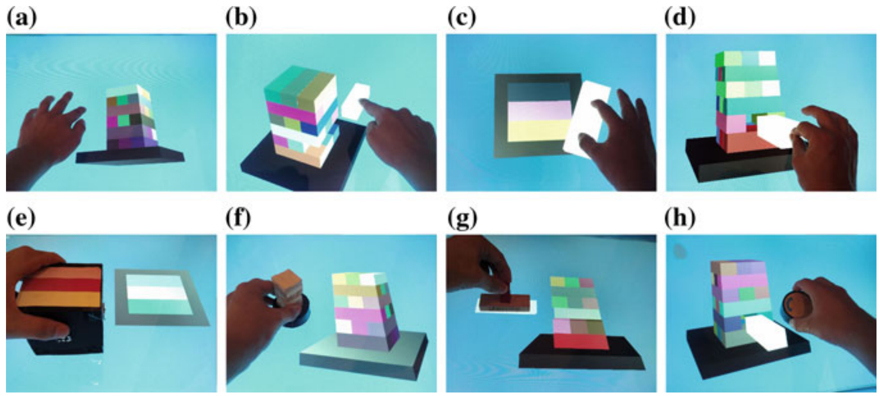

Fig. 2.4 Touch: **a** manipulate camera, **b** move block, **c** rotate block, **d** move block orthogonal. Tangibles: **e** stack—snap camera views, **f** Jenga tower—fine grain camera control, **g** Jenga block—move and rotate virtual block, **h** corkscrew—move orthogonally

the stack. There are no limits when rotating the camera around the stack, however, the vertical rotation is restricted to 90° (directly above to horizontal), so that the table does not obscure the Jenga stack. A gesture can move the camera in both dimensions at the same time. Camera manipulation can be done anywhere on the screen aside from on a selected block and with any number of fingers. This approach to camera movement proved successful in both the usability study and Jenga tournament.

Tangibles
Two tangibles for movement of the camera were implemented. The first is the stack tangible (Fig. 2.4e). This tangible was used in the user study by many of the participants. Placing the stack tangible on the table in a particular orientation snaps the view to one of the five faces (not the top as this would turn the view upside down). This is the only tangible which used the SDK byte tags for recognition. As mentioned earlier byte tags are useful in the case where position and orientation are not needed. For the stack tangible, all the information needed is which face of the tangible is on the table. A different byte tag was placed on each face of the tangible.

The second camera tangible is the fine grain camera stack (Fig. 2.4f), which gives the user fine grain control of the camera. Spinning the fine grain tangible rotates the view around the stack. In addition, moving the tangible up, down, left or right moves the camera view, in the same way a finger swipe would with the same gesture. For example, moving the tangible to the left rotates the camera in an anti-clockwise direction.

2.5.2.2 Block Manipulation

Blocks need to be selected, translated (moved) and rotated. Translation is required in the 2D plane of view and orthogonally to the view.

Touch
Initially translation on the 2D plane was implemented with a touch and drag. However, we found that this would result in users unintentionally moving a block. Therefore double-tap to select was implemented as suggested by a number of participants in the observational study. A single-tap was explored, however because of the number of false positive tap events that can be produced by the table, the double-tap was more reliable. Once a block has been selected, it is able to be moved around using single finger drag (Fig. 2.4b), the movement is restricted to the plane that is parallel to the current view. A block remains selected until released with a double-tap. While selected it is not subject to the physics engine and can be left hanging in midair. We found this was necessary for users to alternate between block and camera manipulation. However, the movement of all the other blocks in the stack is still governed by the physics engine. A double-tap releases a block at which time the physics engine is applied to it and it will drop onto whatever is below it, the stack, table or floor.

Rotation of the blocks is based off well-established two-finger rotation gestures that are typically used on touch devices (Fig. 2.4c). This was popular during the user studies and found to be most intuitive given its familiarity.

The gesture for when a block was to be moved orthogonally, towards or away from the participant, caused the most problems for the participants in the observation study. Yet, this gesture is essential for pulling a block out of a row. We implemented a two-finger pinch to zoom style gesture (Fig. 2.4d). The gesture was initially designed to mimic the grabbing of a block between two fingers and pulling it towards you. However, during the usability study we found that users were confused, the pinch/stretch gesture was reversed for consistency with mobile phones; a pinch is used to zoom out and a stretch to zoom in.

Tangibles
Two main tangibles were developed for manipulating blocks. The first tangible is the Jenga block (Fig. 2.4g). Placing the physical block on a digital block will select it and then movements of the physical block are mirrored onto the digital block.

In order to ensure a close mapping between the tangible and the virtual block, we had to decide how they would snap together. If the virtual block snaps directly to the middle of the physical block, it causes problems when attempting to slowly remove a block from the stack. For example, if a user places the physical block with the midpoint of the physical block on the edge of a virtual block, it causes the virtual block to snap half the length of the block to the center. The result of this is that the virtual block leaps to that particular position often causing the tower to topple. An alternative solution is that no snapping occurs. However, the problem with this is that the virtual Jenga block doesn't necessarily align with the physical Jenga block. Our final solution was that the virtual block slowly tracks to the correct position over a few seconds. In this way, it is almost undetectable by the user but by the time they remove a block from the stack the virtual block aligns perfectly with the physical block.

The block tangible automatically selects the underlying virtual block when it is placed on it, but does not release it automatically for two reasons. First, users are often uncertain of whether they are ready to release a block. Second, the blob tracking can sometimes fail for a moment, if the virtual block is not released this failure does not affect the user's actions. After the usability testing, we discovered that users needed a method consistent with the touch interaction for deselecting a block with a tangible. To do this we settled on a single-tap with the Jenga block; a double-tap would have been more consistent to the touch double-tap, but a single-tap was more reliable.

The second tangible for block manipulation was the corkscrew tangible (Fig. 2.4h). This enables the orthogonal movement of the block towards or away from the screen. Spinning the corkscrew tangible to the right moves the block into the screen and to the left moves the block out of the screen. The movement of the block is orthogonal to the camera view of the selected block. The corkscrew does not select a tangible but operates on the currently selected block. It does not need to be located on the block, it can be anywhere on the display.

2.5.3 Usability Study

The aim of the usability study was to verify the touch gestures and tangibles were easily understood and executable. We refined some of the interactions as reported above. However, we also observed which interaction method was used in given situations. For camera manipulation, almost all participants used a combination of the touch control and the fine grain camera manipulation tangible. The view snapping (stack) tangible was used rarely. The manipulation of the blocks in simple tasks was done primarily with the use of touch. But, interestingly, for the more difficult tasks the users tended towards using the tangible controls. Particularly, the users preferred using the corkscrew tangible for orthogonal movement of a block. The participants expressed that the tangibles were beneficial to their manipulation of the system in some manner. They said that the real-world objects gave them a greater sense of control and allowed for more deliberate actions.

2.6 User Evaluation

To evaluate how well the touch and tangible interaction methods work for manipulating 3D objects in a more realistic environment the user evaluation was in the form of a Jenga knockout tournament. Before any competitive play there was a general training session where all the touch and tangible gestures were demonstrated to the participants and each tried each of the gestures. The tournament was completed in one session that lasted 3 h. Once participants were beaten, they were out of the tournament and were free to either leave or remain and watch. All but two remained until the end. Participants were free to choose how they interacted with the virtual Jenga game: they could use any combination of touch or tangibles. The participants were trained so that they had experience with both touch and tangibles and tried each interaction method before playing in the tournament. There were a number of prizes to motivate participants to choose the interaction method that they felt would best help them win: first prize $50, second prize $30 and third and fourth prizes $20 each.

2.6.1 Participants

There were 9 participants, 2 females, and 7 males, aged from 21–42 (median 28) all were right-handed. All of the participants had previous experience with touch interaction and touch interaction on large touch devices. The participants collectively had much less experience manipulating 3D objects on a normal computer, with touch interaction or with tangibles. An overview is given in Fig. 2.5.

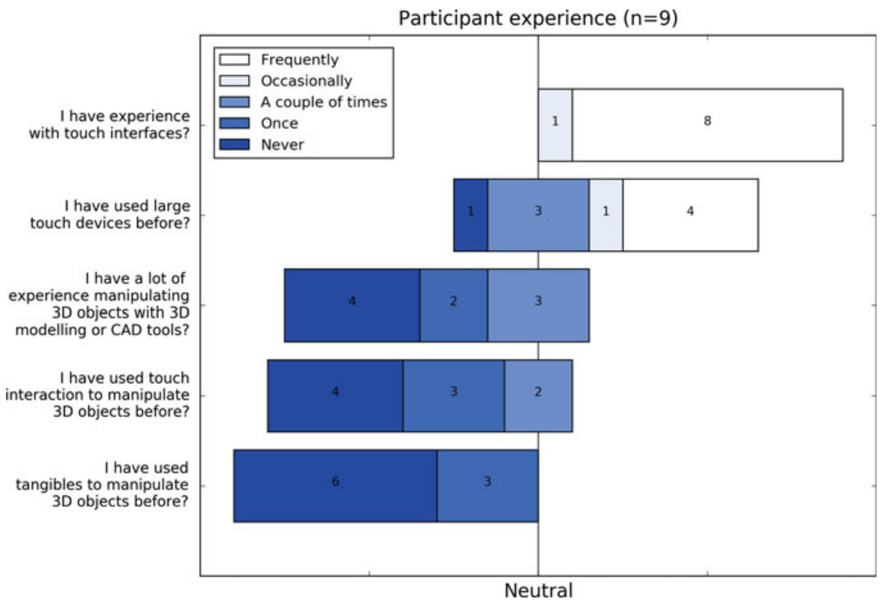

Fig. 2.5 Participants' experience

2.6.2 Tasks

The tournament was structured into three rounds. The first round had each participant compete against another participant. The 9th participant played one of the winners of the first round and the winner of this game progressed to the next round. The four winners of the first round then competed against each other in the second round and the two remaining winners competed against each other in the final round. The first round started with a practice game so that participants could get used to the interaction methods and rules.

2.6.3 Data Collection

A pre and post-task questionnaire was administered to participants. The interactions with the virtual Jenga game were logged providing detailed statistics of what touch gestures and tangibles were used, the time period each was used, and the number of transitions between touch and tangibles. The tournament was videoed. One facilitator ran the tournament and managed the participants while a second facilitator observed and took notes of how participants interacted with the virtual Jenga game.

2.6.4 Data Analysis

The Likert scale responses from the questionnaires and the interaction data logs were analyzed using Jupyter Notebook Pérez and Granger [18]. The freeform questionnaire responses were analyzed by grouping responses with similar themes together, similar to the open and axial coding techniques from Grounded Theory Glaser and Strauss [7].

2.6.5 Results

A number of themes emerged from the data. At a high level, participants found both interaction methods to be generally usable, illustrated by the similar positive Likert scale responses for both touch (Fig. 2.6) and tangibles (Fig. 2.7). The questions related to ease of use, learnability, responsiveness, accuracy and whether participants would use the particular method again.

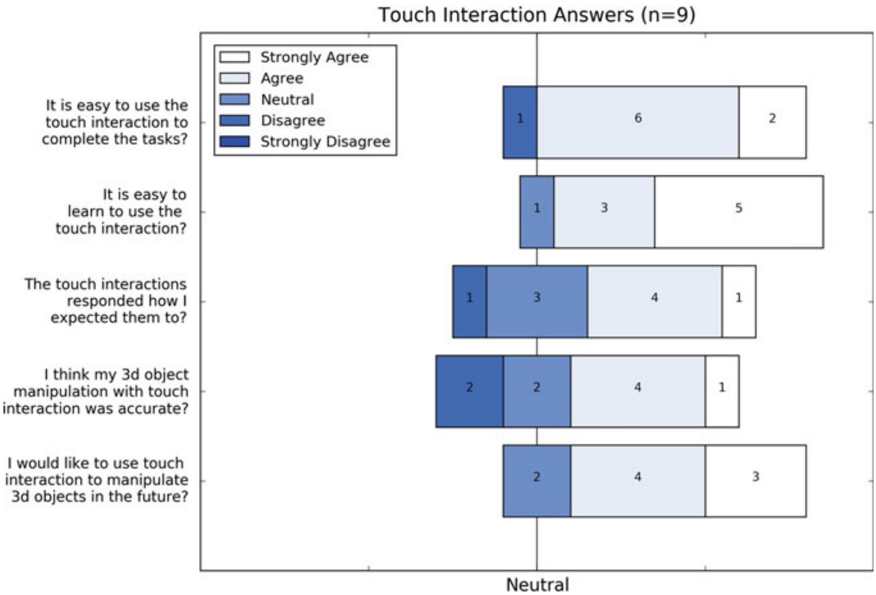

Fig. 2.6 Touch interaction Likert scale results

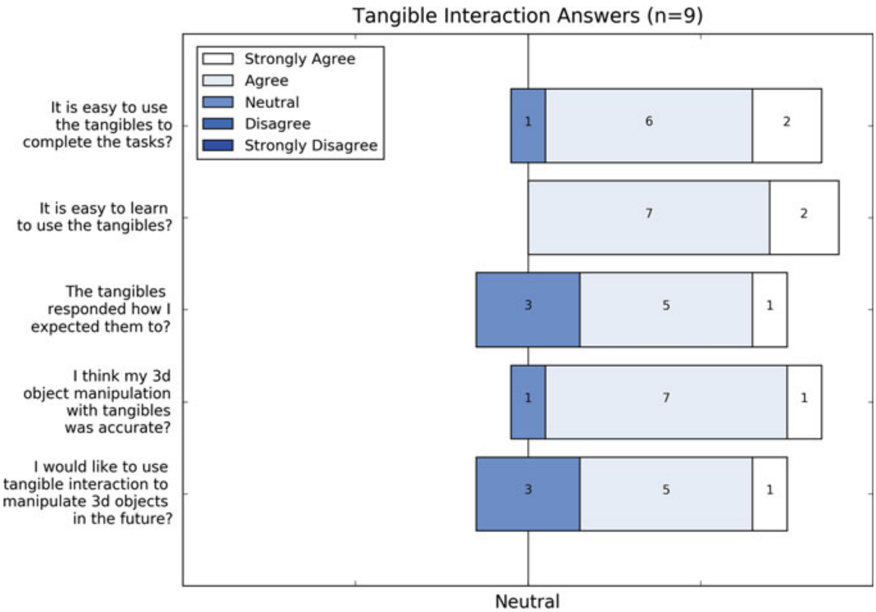

Fig. 2.7 Tangible interaction Likert scale results

2.6.5.1 Touch Interactions

Positive themes regarding touch interaction included, it is easy to use (P1, P6, P7), specifically selecting objects (P9) and moving the camera (P8); it is easy to learn because the gestures are similar to those used on mobile phones (P2, P3, P5); and it is more efficient than tangible interaction as you only need your fingers (P8).

Negative themes regarding touch included poor accuracy (P2, P3, P5, P6, P8), specifically, when rotating blocks (P5, P8) and when moving blocks orthogonal to the screen (P9). To address these areas of interaction, participants thought that using a capacitive screen rather than the SUR40 [21] infrared tabletop would increase accuracy and be able to use the pinch to zoom gesture on any part of the screen would make moving blocks orthogonal to the screen easier (P5).

2.6.5.2 Tangible Interactions

Positive themes regarding tangibles include they are easy to use (P1, P9), specifically to move objects (P1) and change views (P9); they are accurate (P2, P3, P8), presumably, these participants were referring to the corkscrew tangible as it is the only tangible that was used more than touch gestures (Fig. 2.10); lastly, some users appreciated the physical nature of the tangibles, specifically having something to hold onto (P5) and helping them to understand the 3D space (P4).

Negative themes regarding tangible interaction include poor sensing accuracy (P4, P5, P6), especially the stack tangible (P5); a higher learning curve (P2, P5); and there being too many tangibles, which is inefficient (P8) and it makes it hard to remember what they do (P3). To address these issues participants thought that objects could be labeled better (P4) and that the number of tangibles should be reduced (P4, P8).

2.6.5.3 Comparisons Between Touch and Tangibles

The participants were asked to compare the touch and tangible interaction methods (Figs. 2.8 and 2.9), we also logged the time users spent using each touch gesture and each tangible (Fig. 2.10). Two key themes emerged from this data: most users preferred touch interaction; however, the corkscrew tangible was preferred over its touch counterpart.

The Likert scale data slightly favored touch interaction in terms of overall rating (Fig. 2.8) and whether touch interaction was easier to use than tangible interaction (Fig. 2.9, Q1). The participants favored tangible interaction when asked to rate the accuracy of the interaction methods (Fig. 2.9, Q2); however, the only tangible used more than touch interaction was the corkscrew tangible (Fig. 2.10), so this could be in reference to this one tangible.

When participants were asked what interaction method they would prefer if they had to pick one; 7 said they would prefer to use touch interaction over tangible

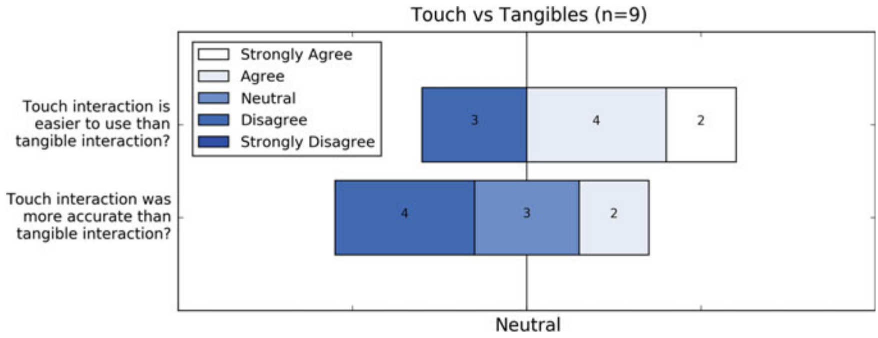

Fig. 2.8 Touch versus tangibles: overall ratings

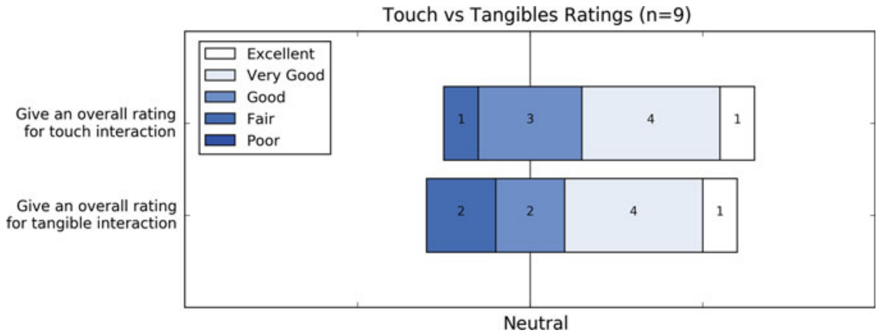

Fig. 2.9 Touch versus tangibles: ease of use and accuracy

interaction, whilst 2 would choose tangible interaction over touch. This reinforces the theme that touch is preferred over tangibles. The data logging also supports this theme, showing that participants used touch interaction much more than tangible interaction in almost all categories, including for moving the camera, translating and rotating blocks and selecting and deselecting blocks. The one area where participants used tangible interaction more than touch interaction was translating a block orthogonal to the screen with the corkscrew tangible.

The last theme that emerged is that 3D control can still be difficult regardless of which interaction scheme is used (P2, P4); specifically, it can be difficult to understand 3D space with the application (P4) and movement relative to the camera is confusing—movement relative to the world may be better (P2).

One observation that surprised us was how quickly some users adapted to two-handed interaction, moving fluidly between touch and tangibles. Figure 2.11 shows the number of transitions between touch and tangibles by each participant. P1, P4, P8, and P9 used a tangible in one hand and touch gestured with the other to rapidly transition between moving the camera and the block; an example is illustrated in Fig. 2.12.

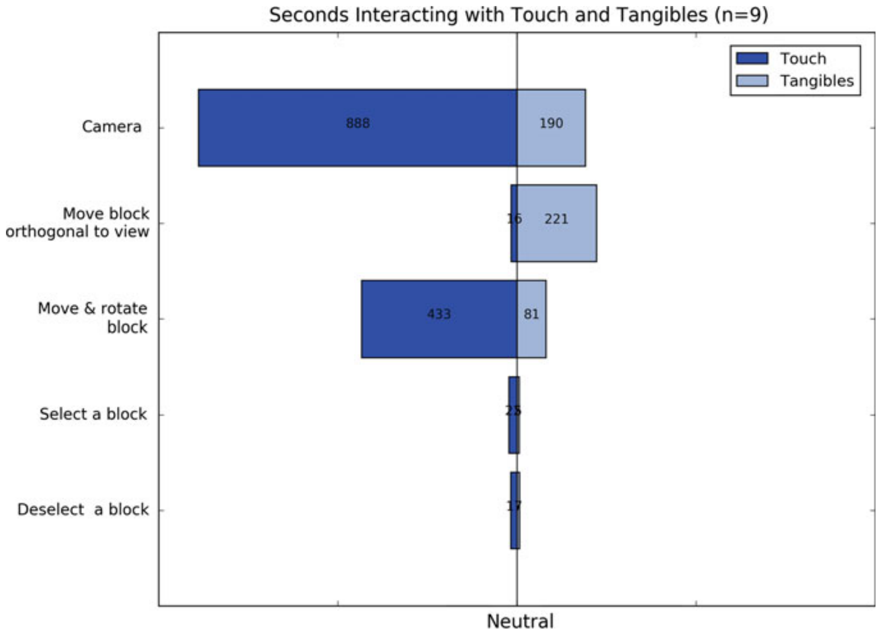

Fig. 2.10 Touch versus tangibles: time breakdown

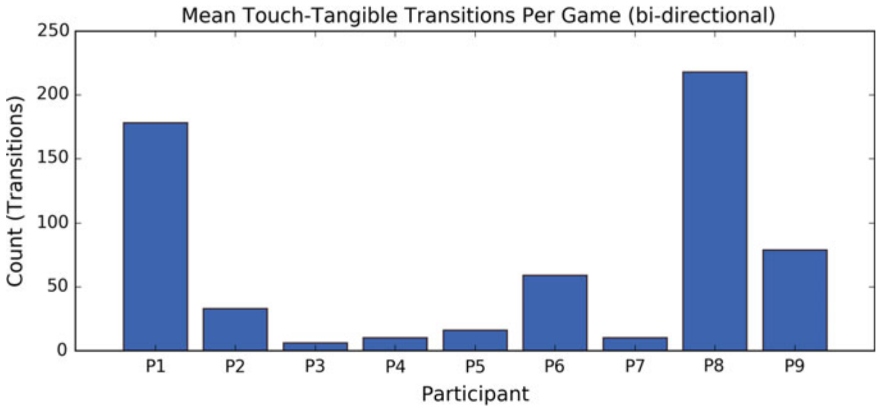

Fig. 2.11 Mean touch-tangible transitions per game (bi-directional)

We noted both collaborative and competitive behavior during the tournament. During a game, the two players would stand close to the table while other people in the tournament watched on from a little further away. The players would swap in and out of the prime interaction position (at the side of the table) as they took turns. The current player would sometimes ask for advice with comments like 'how am I going to do that?' and at other times set out a challenge 'if I take this block out it

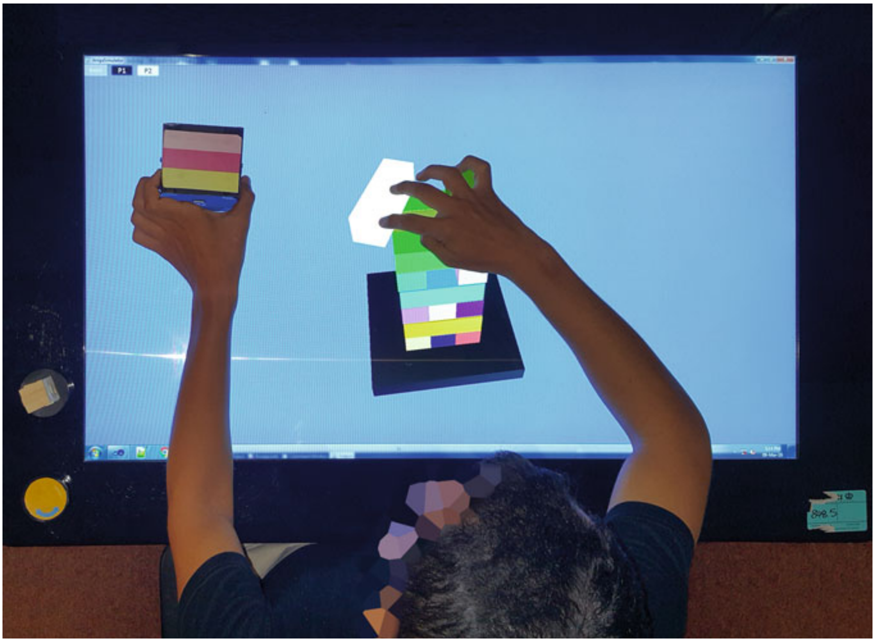

Fig. 2.12 Two-handed interaction example

will make it difficult for you'. Their opponent and other players observing both offered advice and narrated. They made suggestions about how and which block to move next and where to place it. They also commented on the state of play with comments such as 'you can win now'.

2.7 Discussion

The goal of this project was to explore how tangibles together with multi-touch could be used to manipulate objects in a 3D scene. Touch was more familiar to our participants as they were all experienced touch device users. However, they also enjoyed the tangibles and found the interaction to be generally on a par with touch. When asked to choose between the two, most chose touch, this is likely because of familiarity.

We note that users preferred to use touch for most tasks. The exception being orthogonal movements of the blocks where the corkscrew tangible was a strong preference. It could be that a different touch gesture to the pinch to zoom would score better. However, our observational study and explorations during implementation did not uncover a better alternative. Another alternative, suggested by a participant, is to give users the ability to use the pinch to zoom gesture on any part of the screen, rather than just on the block, while we did not trial this, it seems counter intuitive.

Users experienced sensing problems for both touch and tangibles and this negatively affected the results for both in different ways. The stack tangible is the only tangible using the SDK byte tags for recognition. As it was rarely used in the usability study we did not realize how poor its recognition rate is compared to the blob tags. It often did not register, so while users in the tournament tried to use it, they stopped in frustration. Had it worked better, we think that it would have been used much more frequently for aligning the stack to the front view as this is easier and more accurate than touch gesture alignment. The main touch sensing problems occurred caused blocks to jump around and vibrate when moving and rotating them (P5). Use of blob tags, better hardware, and gesture recognizers would solve these sensing problems.

This is the first project to explore using both multi-touch and tangibles, and the first to explore tangibles for 3D object manipulation. It is likely that providing two or more options for the users to complete any task confused some of the user study participants with some claiming there were too many gestures and too many tangibles.

We were surprised at how quickly some participants moved to 2-handed interaction with one hand holding a tangible and the other used for touch. We think that the different affordances of touch versus tangible were quite helpful in this respect. If, as P2 did,[1] the left hand is holding the stack tangible and the right hand used for touch gestures, the affordance of the tangible could be helping balance the cognitive load and reducing the cognitive load of remembering interactions. This is an interesting outcome of the current study that requires further research.

Given the results of the study and the user feedback, for this particular context, we believe it would be optimal to provide two tangibles and six touch gestures. One tangible would be used for camera positioning, with some redesign the functionality of the two camera tangibles could be combined. The second tangible would be used to move blocks orthogonally to the view. The first touch gesture moves the camera as described above. Another set of touch gestures covers block manipulation: double-tap to select, drag to move in the 2D plane, two touch to rotate and tap to release. This combination of tangibles and gestures provides for two-handed interaction and also clearly separates moving blocks on the two different planes.

In this project, we explored two aspects of 3D object interaction. First, there is the need to manipulate the camera view of the world. In an actual game of Jenga, you typically walk around the Jenga tower in order to see what's on the other side. However, this isn't possible on a flat display. On a table, it would be technically possible to track a person moving around the table and alter the view in sync with their position. However, it is more flexible to move the camera and therefore, gesture and tangibles were developed for this purpose. Second we developed

[1]This wasn't picked up by the data logger as much as it should have because the stack tangible was not always detected.

gestures and tangibles for moving objects. Although the Jenga blocks are regular cuboids we believe that the interaction techniques could be applied to any objects in a 3D environment.

Camera control and object manipulation are just two of the controls need for 3D object interaction [11]. Comprehensive interaction would include many other interactions such as complex world navigation, path drawing, and object modeling. To do this with touch alone would require mode changes and overloading of gestures, both of which are generally detrimental, or a complex set of gestures, which are difficult to remember. By adding tangibles to the interaction mix the affordances of the tangibles may make a comprehensive set of interactions both more memorable and easier to use.

2.8 Conclusion

This project explored using touch and tangibles together to manipulate objects in a tabletop 3D virtual environment. These environments are designed for collaborative and playful tasks so we adopted the block building game Jenga as our context. Jenga has the advantages of requiring precise object manipulation and physics alone determining the state of the stack.

While our initial Wizard of Oz observational study guided the development of the touch gestures and tangibles there was little consistency between participants for the most challenging interactions so iterative exploration and testing were required during development.

Returning to our research questions:

RQ1 We found that both methods of interaction were generally usable in the final prototype and acceptable to users. The multi-touch gestures were preferred however, this is partly due to their familiarity.

RQ2 We observed that touch and tangibles can be seamlessly used together for 3D object interaction. Over half of the participants frequently switched between touch and tangibles—some doing so with two-handed interaction—one hand holding a tangible and the other used for touch gestures. While for most tasks touch was the most used method, to move a block orthogonally the tangible was preferred.

RQ3 The tabletop, and interaction methods combined to provide an excellent environment for the 3D competitive-collaborative play.

Providing comprehensive 3D interaction through 2D interfaces has many facets. The ideas explored here could be extended to address other 3D world functionality. In particular combining touch and tangibles may reduce the need for mode changes.

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