Squaring the Circle: How Framing Influences User Behavior around a Seamless Cylindrical Display

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ABSTRACT
Recent research has presented large public displays in novel non-flat shapes such as spheres, curved planes and cylinders, and looked at the influence of the *form factor* on user behavior. Yet, the basic shape cannot be considered in isolation when interpreting the behavior of passers-by around such displays. In this paper we investigate two further display factors, *framedness* and *seamlessness*, that have to be considered in conjunction with the form factor to understand user behavior in front of large non-flat displays. We present the findings from a field study with an *interactive column display* and take a closer look at how these factors influence actor and bystander behavior. Our results show that rectangular *frames* act as a sort of *funnel* for user position and can easily override effects of the non-flat shape on user position and interaction, even though the users didn't recall the presence of these frames.

Author Keywords
Public Displays; Non-flat Displays; Seamless; Framing; Form Factor; Audience Behavior.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Recent and anticipated advances in display technologies have created a research interest in interactive non-flat displays. A variety of prototypes have been presented and the consequences of their form factor for new types of applications have been discussed (e.g., [1,2,3,4,5,11,12]). Some of these prototypes use industry-standard flat rectangular displays as components for building *polygonal* non-planar display configurations, which approximate cylindrical or other shapes. This is a plausible approximation in many respects and such displays are a cost-saving vehicle until completely *round* and *seamless* non-planar

Figure 1. *Seamless interactive column display* at its deployment location.

display surfaces will be available at affordable costs. However, such multi-display solutions are effectively squaring curved surfaces to several flat rectangular screens again, which in turn might affect certain aspects of user behavior differently than the truly round non-planar shapes they approximate. The majority of classical non-planar displays in architecture are curved and seamless; non-planar displays made of flat rectangles in contrast are rare. Structural elements such as domes, arches or columns have long been suitable information carriers that allowed displaying imagery or other information on seamlessly curved surfaces. Also freestanding columns mostly show continuous cylindrical surfaces, with some exceptions such as *citylight* columns designed to hold standard printed poster formats behind glass. If we envision that any surface in urban spaces might eventually be turned into display space by means of novel and possibly flexible display materials, it is likely that many non-planar displays will be truly round and not squared to rectangles.

Several studies reported on the influence of the *form factor* of displays on user and audience behavior [3,4,11,12]. Yet, in many cases more than one display quality might affect the interactive experience, and effects might not always be explained sufficiently by observing one quality in isolation. We propose, that beyond the rough *form factor*, also the *framedness* and the *seamlessness* of the display should be taken into account when investigating how user behavior is affected by such novel displays. We chose the column as a popular example of a non-planar display and conducted a field study with an interactive column, observing actor, spectator and passer-by behavior around the non-flat display for both an *unframed* condition, in which the column provided a continuous surface, and a *framed condition,* in which this continuity was visually broken by gray rectangular frames displayed with the content.

The prototype display we used in the study provides a seamless interaction space around a column using multiple Kinect sensors with overlapping ranges. It allows gestural interaction with the playful content from any position within a certain distance range. Our study reveals that the two conditions of the column (*unframed* vs. *framed*) produce different audience behavior with regard to user position and interaction between users: Subjects showed a preference for assuming a central position in front of each rectangular frame, but spread out much more evenly in the absence of frames. What makes this even more exciting is the fact that virtually none of the subjects did recall to have noticed the displayed frames. This influence of framing on user behavior can be accounted for when designing applications for non-planar public displays.

QUALITIES OF NON-FLAT DISPLAYS

Since we argue that slight changes of shape, size, surface or framing can influence how a display is experienced and understood and how users interact with it, let's first define the display attributes investigated in our study.

Form Factor

The *form factor* of displays can – at the top level – be *flat* or *non-flat*. Most non-flat displays are curved, and the convex or concave bending of the display in relation to the user influences how far they cover the field of view. Closely connected to the form factor is the notion of *surface roughness*: A cylindrical display can, for example, have the shape of a *circular cylinder* or of its approximation by *polygons,* such as a *hexagonal* or *octagonal* prism (see Fig. 2).

Framedness

The frame of a screen has been found to influence the body orientation of viewers and where they position themselves [3]. Three types can be distinguished: *framed rectangular screens* (e.g., classical 4:3 or 16:9 format), *semi-framed screens* that lack a left and right boundary (e.g., columns or very wide banner-like flat displays) and *non-framed screens* (e.g., spheres or hemispheres with a boundary on one side).

Seamlessness

Seamlessness or a *seamless transition* differentiates round non-flat displays from discontinuous spatial display configurations. Non-flat displays are *seamless*, if their display surface is not interrupted by a visible *bezel*, *frame* or any kind of *edge*. According to this definition, e.g., a polygonal multi-display made of flat faces is not seamless because of its bends (compare Fig. 2). While to a certain extent, a rough common *form factor* of different displays can trigger similar effects, displays with a smooth seamless surface might elicit different audience behavior than arrays of flat rectangular or framed displays. To better understand the effects of framing, we compared an *unframed* and a *framed* condition of the same seamless column, in order to explore the influence of just framing on actor, passerby and audience behavior.

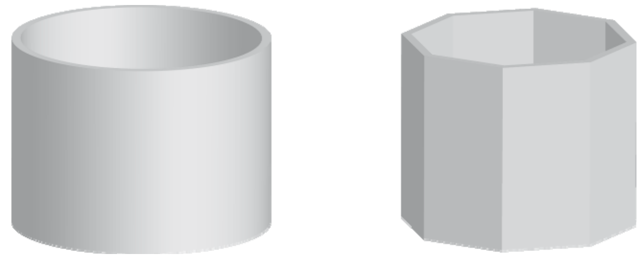

Figure 2. *Circular cylindrical display* and *Octagonal display configuration* composed of eight flat displays, as examples for non-planar displays with a similar form factor but different *surface roughness*. While the circular display is characterized by a *seamless surface*, the octagonal display may also show characteristics of the flat rectangular displays it is composed of.

RELATED WORK

The work presented in this paper is related to large and interactive public displays and to field studies on such displays in general and, more specifically, to non-planar displays, work on framed and frameless displays, as well as seamless surfaces on such displays:

Interactive public displays

Studies on public displays generally address problems such as engaging users and raising attention to interactivity [10,15], interaction techniques [10,22] and collaborative interaction [20]. Several researchers have proposed useful models, frameworks and taxonomies to describe display types [16], interaction phases [6,22], audience behavior [10,15,17] and social mechanisms between users such as performative interaction, that also apply to public displays [7,19]. Also spatial aspects of large displays have been evaluated [8]. To investigate user behavior around interactive public displays, observational field studies combined with interviews have been the prevailing evaluation method [6,10,12,15,17].

Non-planar displays

Non-flat displays are a trend topic discussed from several research perspectives ranging from natural interaction techniques [1,2,21] to collaborative interaction with such displays [4]. Preferred shapes for investigation include hemispheres and spheres [1,4] as well as cylinders [5,11]. In the context of public displays, Beyer et al. [3] compared a large cylindrical display to a flat rectangular display in a lab study and showed that users were moving and positioning differently in front of these two displays: users accumulated within a sweet spot in front of the framed display but were moving within a circular space around the cylinder. Koppel et al. [12] examined different configurations of chained displays (hexagonal, concave and planar array). Their study confirmed that each configuration triggered different actor, by-stander and group behavior, depending on the rough *form factor*. Our work will add to these insights by examining the additional display quality *framedness* separately from the rough *form factor*.

Seamlessness and Framedness

Within the area of digital office environments, Hennecke et al. [9] investigated the effect of different physical transition types (bezel, edge and curve) on dragging behavior across a combined horizontal and vertical display workspace. Beyer et al. [3] introduced the category of semi-framed displays in which the virtual representation is only contained by boundaries at the top and the bottom. Their study showed that people tend to position themselves in a center position in front of a flat and framed rectangular display. It remains open to what extent the planarity and the framing of the display contributed to this effect, especially since Koppel et al. [12] obtained different results with a cluster of six even-lined rectangular flat displays. Pinhanez et al. [18] discuss the advantages and limitations of frameless interfaces in ubiquitous environments. On the basis of several examples they explain how the frame functions as a container for interactive and non-interactive applications, and how a frameless display can be used to better connect the application to objects in the environment. They also point out the possible influence of implicit frames, for instance created by the faint background lit by projections, and present a technique called *real world framing*, where frame-like elements of the physical environment are intentionally used as a substitute for traditional framed displays, acting as containers for virtual information and interaction.

All of this related work investigates single display qualities such as the basic *form factor*, the *framedness* or *seamlessness* of interactive surfaces. However, because these qualities were mostly investigated in isolation from each other, the differences between curved surfaces and piecewise flat or polygonal display configurations are still unknown. We try to fill this gap with a field study in which we use a truly curved cylindrical public display in both an *unframed* and a *framed* condition in order to explore whether there are different effects on actor, passerby and audience behavior.

INTERACTIVE COLUMN DISPLAY PROTOTYPE

In order to compare an *unframed* and a *framed* not-flat display, we chose the digital and interactive counterpart to a popular and historically proven shape, the *digital advertising column*. Our aim was to create a situation, in which we could compare the two variations under the same external conditions. For this reason, we used the same large interactive cylindrical screen to simulate both conditions, instead of comparing it to another polygonal display setup.

Seamless Cylindrical Screen

The display of our column is a round cylindrical screen and completely *seamless*. It was realized with a rear-projection setup and an acrylic screen from one mould, as we wanted to avoid any edges that could influence user behavior. The *framed* condition was realized by displaying gray rectangular frames around segments of the content. Since this solution does not create the flat faces of a polygonal display, it allows us to isolate the *framedness* variable and investigate changes in user behavior by just activating this one switch. To use the same hardware prototype for both conditions also allowed us to maintain all other parameters constant that could influence user behavior. This includes display materials, illumination technology, appearance of the column and installation site.

Seamless Interaction Space

For our study, we considered it important that the interactive column provided a seamless, circular interaction space around itself. For investigating the influence of boundaries and frames on user behavior, it is important that the sensor technology does not restrict interaction by invisible dead zones. In order to realize a transition-free circular interaction space around the column, 8 Kinect sensors were needed to cover the entire surroundings, and a high performance hardware and software setup guaranteed fluent interaction even with a larger number of users. To realize a continuous interaction space around the column, several issues with regard to overlapping sensor regions and a consistent representation of skeletons on the screen had to be resolved. We conducted preliminary tests with the official *Microsoft Kinect SDK,* which demonstrated the absence of interference between two sensors, even when a nearly 100% overlapping of regions was reached. Doubly recognized skeletons were rejected by a simple filter system. We used a fixed angular and vertical arrangement of the sensors and fine-tuned every transition area to maintain a nearly consistent mapping between body and screen coordinates. In the final software used during the study jitter of the skeleton in the transition areas when users were moving around the column was in the same order of magnitude as jitter produced by the sensor itself.

Hardware and Software

The cylindrical column is 2.10 meters high and its corpus carries a 4:1 rear projection screen with a diameter of 1.3 meters and a height of 1 meter. The rear projection uses 4 projectors and 4 foil mirrors. The resulting distortion and overlapping of the images is corrected in real time using proprietary software for image equalization and edgeless blending. The 8 *Microsoft Kinect for Windows* sensors were integrated into the column corpus at equal angles and as unobtrusively as possible, to avoid a situation in which subjects would recognize the sensors and consciously or unconsciously align themselves to them (see Fig. 3).

Figure 3. 8 Kinect sensors integrated into the housing provide a seamless interaction space around the column, PC hardware runs the distributed Multi-Kinect application for our study.

Running a setup with 8 Kinect sensors in parallel required a substantial amount of computing performance, and as each of our Core i7 PCs could only serve a maximum of 3 Kinects in parallel at acceptable performance, we had to develop a distributed application that exchanges skeleton and depth data between several Kinect clients and a server for data aggregation and rendering. Our final setup also handled mass interaction properly, when larger groups of people approached the column simultaneously. In these cases, a maximum of 16 users were served with a skeleton representation simultaneously, while the rest was ignored. The application was programmed using C#, the Microsoft Kinect SDK and Windows Presentation Foundation (WPF) for the GUI. The final hardware setup consisted of 5 computers for running the application, 4 of which were used as Kinect clients, 1 as the Kinect and rendering server, and 2 of these also concurrently for image correction. We used 2 additional computers for the camera-setup of the observational study we conducted.

FIELD STUDY

The objective of our field study was to (1) investigate in general how passers-by would behave around a completely round cylindrical display in the wild and to (2) explore in particular our main research question, whether a non-flat interactive cylindrical display with a *seamless surface* would affect user and bystander behavior differently from the same display with added visual *frames*. To test and refine content and interaction techniques used with the column, we conducted several weeks of pretests in a former university library with students from our lab until the system was robust enough for a long-term deployment in the wild. The field study itself was conducted over a period of 4 weeks in a public setting. We used field observation combined with multi-perspective video analysis, logging, and semi-structured interviews.

Deployment

The column display was deployed for four weeks in the entrance hall of a university building open to the public. The highly frequented building housed courses of many different disciplines (e.g., philology, dramatics, physics, religion or social sciences) but also non-academic courses, exams, a cafeteria, cultural events and other non-recurring events. It thus provided a steady flow of novice users. The column was positioned in a central location within the large entrance hall, where the main walking paths from all directions intersect. In a field overview, we had found that both outdoor and indoor columns are often positioned in such freestanding and central locations, where they can be seen well and be approached from all sides. Indoors, advertisers sometimes also use existing structural columns, usually in a centric position of halls, and turn them into advertising columns with a round enclosure, which resembles our deployment situation (see Fig. 4). Two structural columns were located on both sides of the interactive column, but observational data didn't show any relevant effect on user positions or trajectories while interacting around the column. The column was booted up daily at 9 am and shut down at 7 pm, the time when the frequency of passers-by usually dropped.

Displayed Content

As the content itself naturally influences the behavior of people in front of a public display, to an extent that can even override effects caused by certain display qualities, we tested several applications in the pretests and chose a very simple game which follows a common Kinect game principle but doesn't demand that the users perform very specific or extraordinary gestures. The game in fact is just an invitation to play with one's own representation on the screen, move freely around the column, and kick falling balls in any direction or to other players. Again, we considered it important that also the content was continuous around the column and would not influence user positions e.g. by regional limitations. As the user representation, we first intended to display a cut-out mirror image of the user on the screen as proposed by several researchers (e.g., [14] and [15]), but due to distortion of the life-size color representations of users on the curved surface and because we were unable to display all body parts, we decided to use a more abstract and space-saving "Skeleton" representation. This comic-like representation was also rated the most entertaining by our students in the pretests. To make users aware of the interactive capabilities of the column in situations in which they were not approaching it from an angle such that the Kinect could detect a skeleton from the very start, we used an eye-catching particle representation triggered only by depth information to attract passers-by until their skeleton could be detected.

Conditions

The content described above represents the *unframed* condition of our *framedness* variable. The *framed* condition was realized by displaying gray visual frames on the screen. To isolate *framedness* as a single variable, the frames were just a visual overlay on the frameless application. Users and objects could seamlessly transition between frames and were displayed at any position behind virtual frame bezels. Each vertical division line between two sections had a width of 2.8 cm. This simulates the bezels of two adjacent flat screens plus the gap between the displays caused by the bend. In a field overview with available flat screens the minimum bezel of one single screen had been determined as 1.2 cm. The frames divided the column into eight

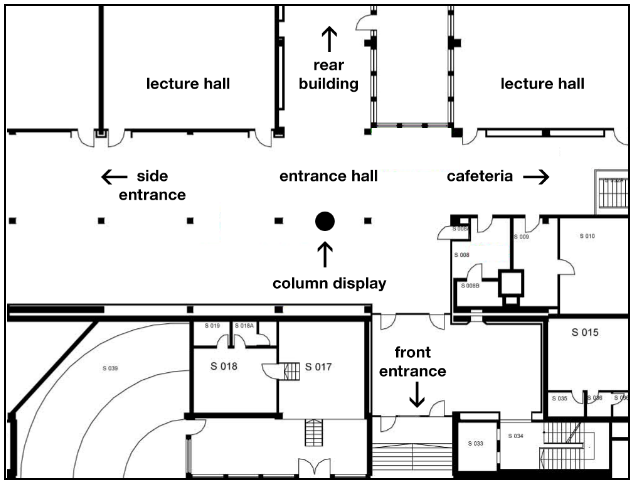

Figure 4. Floor plan of the deployment location for the column display. It was installed at a main intersection within the entrance hall of the building.

rectangular sections, resembling an octagon and resulting in frames with a 16:8 aspect ratio, thereby approximating a classical screen format. We considered randomizing the positions of the frames to eliminate any possible effects of the sensors, yet this would have made the experimental conditions and the analysis of user positions much more complex (see description below). While switching the content many times a day can be assumed to minimize temporal effects with recurring users, in our case there were strong arguments for which we decided to switch the experimental conditions weekly. As the population (students, attendees of continuing education, events etc.) and traffic in the entrance hall were alternating greatly between and within days (e.g. at peak times between lectures), but similarly distributed for the same days of the week, we decided to maintain the same conditions over a week. In particular we wanted to avoid a change of conditions at times when users could observe it, thus possibly also influencing user behavior or judgment.

Data Collection

As part of the field evaluation, field notes were taken, video and log data were collected, and semi-structured interviews were conducted after the deployment.

Field Observation

During the whole evaluation period, one field rater was hidden in a separate, concealed chamber where he could not be seen or anticipated, taking field notes while following what happened and controlling the observation software. We installed a multi-view camera system to be able to observe the whole interaction space around the column and the approaching pathways. A total of 4 cameras recorded video from different perspectives. The building's gatehouse not far from the column provided an unsuspicious place from which the building's desk officer could also monitor that everything was going well with the column without attracting attention.

Video Recordings

Over the whole evaluation period, videos were recorded for a later qualitative review of what was happening and for quantitative analysis of the two study conditions. We refrained from advertising openly that video was recorded in order not to influence the subjects' behavior. In our favor, the British Psychological Society suggests that observational research is acceptable in situations where those observed can expect to be observed by strangers [13], which was the normal situation in our setting.

As we were interested in absolute user positions and trajectories from different perspectives around the display, and also wanted to observe interactions of user behavior and screen effects, we discarded the possibility of using the Kinect sensors integrated into the column corpus for video data acquisition. Video streams from 4 different camera perspectives were automatically synchronized to quad view recordings using the *Noldus Media Recorder* software.

Logging

The following log data were collected from the Kinect sensors for each interaction during the evaluation period: *date*, *time*, *duration*, *absolute position on the screen, relative position to the current frame center*, *distance from the column* and *body orientation (frontal, sideways)*. Since this log data also included all kinds of unaware or unintended interactions by currently non-involved bystanders, and since it is was not possible in our highly-frequented environment and 4-week deployment to filter out only the intended interactions and to automatically correlate consecutively detected skeletons to single individuals, logging data was only used for manual verification of the data of the video analysis.

Semi-structured Interviews

As we had to take into account that there were also regularly recurring passers-by (students and university staff), the semi-structured interviews were only conducted at the last day of the study and the weekdays afterwards, involving only people that would not interact again with the column. A total of 79 semi-structured interviews of about 10 minutes each (8 subject areas, 24 questions) were conducted following a manual by 2 researchers in a place outside of the university building. The standardized part of the interview was carefully designed with regard to the order of questions and wordings to minimize context effects. The flexible part of the semi-structured interview's method allowed us to inquire further in the case of equivocal or individual user statements. Generally interviewees were first asked open questions on subject areas, then gradually inquired further about relevant details they did not mention by themselves. Subject areas were, amongst others, the approaching pathway, cognition of the installation, number of encounters, attributes and perceived visual elements, functionality, interactivity, assumed purpose of the installation and suggested improvements.

Data Analysis

The analytical methods of our study contributed to each other and were interrelated with each other in different ways. The observations of the field rater contributed to a large part of the qualitative findings of the study. For the quantitative evaluation of user positions around the column video coding was used. The video analysis also allowed us to review and add to the qualitative findings from the field observation. In turn, field notes were also used as subsidiary input for interviews and the video coding (raters were able to look them up) and contributed to the preliminary extension of the coding scheme with behaviors going beyond user positions. The role of the Kinect log data was, for the stated reasons, restricted to the review of inconclusive situations in the video sequences.

From the video material we drew a sample of 10 consecutive weekdays and about 3 of the daily peak hours for analyzing the effect of our categorical independent variable *framedness* and its conditions *unframed* and *framed*. 33 hours of video material were analyzed in detail qualitatively and quantitatively by 2 independent raters, using the *Noldus Observer* video analysis software. The dependent variable was the position of each subject relative to the frame. We discriminated a user position *within the central 50 percent* of (the angle covered by) a frame from a user position *in the remaining boundary area*. This created a categorical two-level outcome variable. Since small changes of user positions occurred constantly in our field setting, positions could not be scored in a practical way for more than these two values. To allow a clear assignment of position codes, the videos were augmented with a *grid mask* which was derived from preliminary video recordings with test persons and calibrated with Kinect log data and visual markers on the floor (see Fig. 5).

The coding scheme also contained the behavioral group *interaction type* for each subject present with state events *Actor* (person interacting), *Spectator* (person watching others interacting) and *Attentive* (attentive person not watching others), as we were interested in the correlation between these states and our position variables. Generally or temporarily *Non-involved* persons around the column were not scored. The attentive behavior was later also disregarded, as it occurred rarely for persons stopping and usually distinct positions could not be identified. Positions were always scored simultaneously with the intervals of actors and spectators so that they could be nested later. Short interactions of less than 5 seconds were disregarded in later calculations and position changes below 2 seconds were also filtered out. Situations in which the user position was inconclusive while interacting (e.g., when constantly moving around the column or position) were so rare that they were not quantitatively scored. Raters underwent an initial training, and inter-rater reliability was calculated for all codes. Agreement was substantial for both interaction states (Cohen's Kappa = 0.69) and user position states (Cohen's Kappa = 0.61).

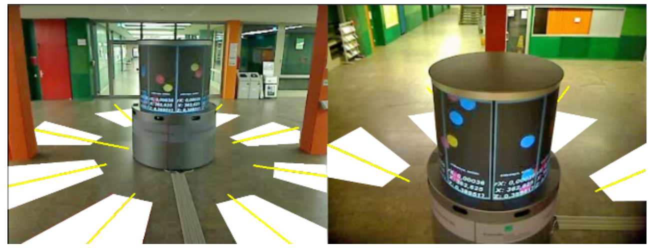

Figure 5. Two Perspectives of the multi-view camera system augmented with additional information for the video coding.

RESULTS

Within the 10 days or 33 hours of analyzed video material, a total number of 762 interactions was scored, and 205 people watching others interacting were observed. On average, users spent 40.9 seconds actively manipulating content on the column and 21.6 seconds watching others. The total time of attendance ranged from several seconds to more than one hour.

General Observations from the Field and Video Recordings: How People Interact with the Column

We observed that a large number of passers-by took notice of the column. Passers-by noticing the column but initially heading to different directions slowed down or stopped, before approaching the column; people approaching the column without having to change their original walking path often only stopped when directly standing in front of the column. Interestingly, nearly all passers-by, once they had shifted their attention to the column, appeared to almost immediately understand that the column was interactive (on average after about 1-2 seconds). We observed several first-time users (identifiable as such by their behavior) that already started interacting while still approaching the column from the distance. This was surprising to us, as we didn't expect that users would recognize the abstract skeleton representation as their virtual counterpart so quickly. It facilitated an effective initial interaction, probably also because many users were approaching the column directly and frontally. Passers-by with deviating walking paths were usually first looking at the column for several seconds before they stopped and redirected to the column to start interaction. Similar to former observations in related research, users often (a) started interacting almost immediately after unintentionally interacting with the display when passing by, or (b) first watched what was happening around the column for a certain period when they had become attentive by seeing other people interact with the display. We observed individuals, pairs and groups interacting with the column, but especially groups attracted the attention of further passers-by, which sometimes resulted in situations with 10 or more persons interacting simultaneously. When engaging with the column, users were playing together, imitating others, showing off or losing themselves while exploring the content. Concrete behaviors included kicking the balls with feet or hands, jumping, boxing a partner, joining hands or dancing.

Findings from Field Observations and Video Recordings: User Position in front of the Unframed Column

In the *unframed* condition, we observed that users were taking diverse positions around the column. Usually, people were starting the interaction from the direction from which they approached the column. As these positions depended on popular pathways, there were sections all around the column in which people approached more often than within others. After *interacting* for a while, users often stopped interacting, moved around to another side of the column and re-approached it to start interacting within a different area. Users would assume a more or less arbitrary position within the circular interaction space, both within sections that in the *framed* condition would be assigned to either the central or the boundary position in relation to the frame.

Figure 6. Users assume diverse positions around the unframed column both when interacting and when watching others.

Findings from Field Observations and Video Recordings: User Position in front of the Framed Column

In the *framed* condition, we observed already during the field observation a clear preference for certain user positions. First, similar to the *unframed* condition, people were stopping where they approached the column. When starting to interact, however, users repositioned themselves such that they were standing centrally in front of a rectangle. While users still engaged with all visual elements of the content (skeletons, balls etc.) as before, we could not observe that they gave any attention to the virtual frames or that they tried to integrate them into their play (see Fig. 7).

Figure 7. Users position themselves in the central area in front of rectangular frames especially when interacting.

Statistical Results from the Video Analysis:

Analysis showed that in the unframed condition 57% of users stopped within the central and 43% within the boundary position. Nearly the same distribution could be observed by just looking at the active time intervals during which users were interacting with the unframed column (59% to 41%). Of the people watching others, 41% assumed a central position and 59% a boundary position. These numbers show that even for the unframed condition there was not a completely even distribution of positions around the column, and also reveal a contrast between the *actor* and *spectator* roles in preferring certain positions. Looking at actors and spectators combined, in the framed condition 66% of all persons involved around the column preferred the central position in front of the rectangle, while just 34% preferred standing at the boundary. The association between the *Frame* and whether or not users would assume a central position is significant $\chi^2(1) = 9.497$, $p = 0.0002$. Looking at user's activity nested with preferred positions, no change could be observed for *spectators*, but a significant effect exists for *actors* with central positions increasing from 59% to 71%, $\chi^2(1) = 14.328$, $p = 0.00015$.

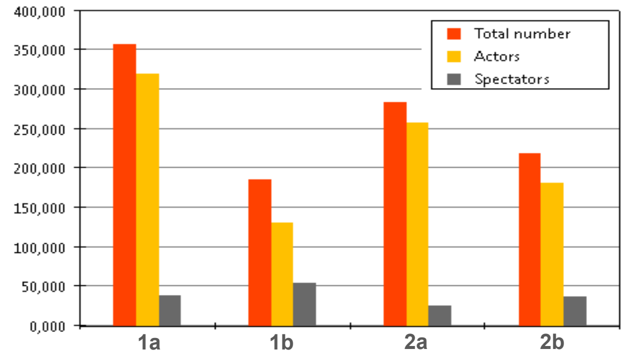

Figure 8. User Positions in front of the Column: Total number, number of actors and spectators in central (a) and boundary (b) position states around the Framed (1) and the Unframed (2) Column. The central positioning in front of frames can be attributed to the interacting behavior, while with spectators the ratio of central to boundary positions remains constant.

Findings from Field Observations and Video Recordings: Positioning of Singles, Pairs and Groups

In the *framed* condition, individuals assumed a position exactly within the center of the frame if they were the first persons on-site. For pairs, we observed two different patterns: when cooperating, they would either stand close together or behind each other directly in the center of the same frame, partly even restricting their movement possibilities. It seems that unconsciously, none of the partners would step out of an invisible marking line, denoting the area directly in front of the frame (see Fig. 9). A similar behavioral pattern shows for pairs cooperating or competing from adjacent positions: each partner would occupy one of the slightly distant positions of two neighboring frame centers, thus trying to reach their partner with long arms when trying to touch or box the partner. In contrast, in the *unframed* condition, partners stood next to each other at comfortable distances. Whenever only one partner interacted and the other one just watched, the passive partner stood alongside the active one, and thus in the framed condition where a boundary would be. For larger groups we observed that people joining the interaction took possession of the radially dispersed sections around the column that were centered in front of frames. If multiple of those sections were already occupied, additional users waited within the in-between zone, watching the active player and ignoring their own screen representation divided by the line of a frame, until it was their turn to enter the central position in front of the frame.

Figure 9. Pairs and groups disperse to central areas in front of the frames in equal manner when assuming an active role. Pairs often impede each other in front of frames. Passive bystanders also don't mind waiting within the boundary zones.

Results from the Interviews: Noticing the Frames

The majority of people were very cooperative when asked to participate in the interview. Of the 79 interviewees, most were students (65) and university staff (12) from diverse disciplines, age ranging from 19 to 66 (average 26). A total of 59 of the 79 interviewees (75%) understood that the column was interactive and what they could do with it. From the 20 people who recognized that a digital column was installed within the entrance hall, but didn't notice interactivity, most stated that they had been in a hurry or had been taking paths from which they would see the column only from a distance. Asked for the anticipated purpose of the column, there were diverse answers, but a majority thought the purpose was entertainment of students. When asked about attributes that would apply to the column, the most frequent answers were (open question): *interesting* (16), *modern* (16), *funny* (14), *colorful* (7), *advertent* (6), *large* (6), *entertaining* (5), *technological* (5), *cool* (5), *moving* (4). The majority of people who understood interactivity were able to describe quite precisely, what they could do with the column. They described the representation as imitating their behavior, also recognized the other interactive screen elements such as the colored balls, and that it was funny to cooperate or compete with partners. Most used the term stick-figure (63%) to describe what they had seen on the screen, some also used the term *mirror* (8), even if no mirror representation was used. Most interestingly, when asking again in more detail, only one out of 79 interviewees stated to have seen the rectangle (in the frame condition), while none of the other interviewees could remember them, even regularly recurring users and although it was the last condition that was displayed right before the interview. Our semi-structured interview method allowed us to inquire further until we were sure interviewees were not remembering the frames. We first asked an open question: "Which elements were displayed on the column?" We then inquired about all the elements on the column they did not mention. In one of the sub-questions, we asked whether they noticed a gray rectangle or frame on the column. Depending on the responses of interviewees we explained in more detail what we meant by it. Following this procedure we tried to rule out possible misunderstandings as well as effects of social expectancy. Many interviewees stated on their own initiative that interacting with the system and watching others was entertaining and they had enjoyed it, which also confirms our observations.

SUMMARY OF FINDINGS

In the following, we'll summarize the findings from the different analytical methods and describe how they are interrelated with each other.

Framedness influences User Positioning

The numbers from the video analysis confirm our field observations that there is indeed a significant difference in user positions around the column when switching on or off *framedness*. The framed condition invited users to step into a restricted area aligned to the center of the displayed frame and kept them from leaving it. Looking at the behaviors in more detail, users repositioned themselves to the central areas as soon as they started to interact, while bystanders were not influenced by the frames. The numbers even reveal a small reverse distribution for spectators, which – according to our qualitative observations – we attribute to the fact that bystanders were often standing alongside their active, centrally standing partners.

Framedness influences User Cooperation

The pattern of a central positioning in front of frames repeated itself for single users as well as pairs and members of groups. People started to occupy the frame sections around the column and accumulated towards their centers, while the distance between users in neighboring sections increased. We observed that – in contrast to the *unframed* condition – pairs that decided to stay in front of the same frame, or pairs that were cooperating from neighboring frame centers, impeded each other when trying to interact and refusing to step out of the invisible area in front of the frame at the same time. While this was a qualitative observation and team play was not scored separately in the video coding, such incidents could be observed regularly whenever active roles or central positions were recorded for two or more subjects simultaneously.

Seamlessness and Positioning

The slight alignment to sections in the unframed condition revealed in the video logs was unexpected and we assume that either (1) the specific walking paths within the entrance hall overlap by chance with regions assigned to the central user positions or (2) elements of the column such as the still visible sensor coves might have been salient enough to implicitly drive users towards a certain position. While this doesn't invalidate the difference in positions of our tested conditions (differences might even be larger in an assumed perfect environment), it shows that even with a completely seamless display there are other factors that can influence user positioning and might not be perfectly eliminated.

Blindness for the Frames

Most interesting is the result that interviewees did not recall the presence of the frames. This is consistent with our field observations that people ignored the rectangular frames in their interactions, although they influenced their positioning. Since we cannot assess people's subconscious at that moment, we cannot conclusively determine whether the self-alignment to the rectangle happened unconsciously, or was considered obvious and users gave no further thought to it.

DISCUSSION

In our experiment we controlled *framedness* on a cylindrical display, while *seamlessness* remained constant. Analysis showed that by just switching on or off the frames, user positioning around the column significantly changes. Just adding visual frames to the screen display attracted users to the center areas in front of the displayed frame. These findings are in line with the results of Beyer et al. [3], namely that different display formats can influence where users move and position themselves. Adding to these insights, the user positions around our simulated octagon show, that also the visual structure of a shape more complex than a single rectangle can lead to the effect that people assume certain positions, and that this effect also depends on their role (actor/spectator).

Since we simulated an octagon with our seamless column, we could not fully simulate actual polygonal displays. However, since we found that only displaying a gray rectangle on the screen can already alter user behavior, we argue that polygonal displays with their flat faces and straight edges creating a visible rectangle and indicating a clear direction might even have a stronger effect on user positions than the one our experiment showed.

While in our study we focused on isolating the *framedness* variable on the same seamless display, the generalization of our results is limited with regard to other shapes of large displays and their interrelation with frames. Future work could e.g. investigate how overlapping regions of frames on concavely curved displays affect user behavior. In our case, where the non-flat display is curved convexly, *framedness* created distance between users, and cooperation between two users from adjacent positions of two neighboring frame centers was restricted. Using the terminology of Fischer et al. [8], gap spaces were created around the column by the frames and thus by the design of the system itself. The creation of distance between users may also explain, why in the study of Koppel et al. [12], where flat (and hence at least implicitly framed) displays were used, passers-by belonging to a group would not disperse to other screens of the hexagonal display but return to the first actor, assumedly because of the large distance the sections created between the players. In our study we also observed that users approached differently than reported for the hexagon. While different deployment sites, walking paths and content types of both displays are possible explanations, also the consequences of *framedness* and different *surface roughness* on the passersby's recognition of the interactive content could be the causes. Our results show, that in addition to the form factor, also the framing of a display influences how people adjust in front of it, and that each factor should be taken into account separately.

DESIGN RECOMMENDATIONS

On the basis of our experiment with the column display, we derive the following recommendations regarding *framedness* that, carefully considering the effects of other display qualities, may also apply to other forms of displays:

Consider the Effects of Frames on User Positioning

Frames draw users towards the center of the displayed rectangles when they start to interact. Often, single flat rectangular displays in public space are positioned such that they are facing the direction of approaching users to be best seen. Inversely, frames can be used to actively draw users to certain positions. This could help e.g. to establish a certain social constellation around the display. On the other hand, the number of optimal user positions right in front of the frames is limited, and therefore frames may not be useful if the aim is to maximize available user positions.

For Close-by Interaction, avoid Frames

Frames can restrict the movement options of two or more people trying to interact within the limited space in front of the same frame. For this reason, they should be avoided if close-by interaction between users is intended. Instead, in the case of our cylindrical display the unframed condition allowed pairs to stand side by side at comfortable distances. Such invisible restrictions of the interaction space caused by frames should be considered when designing applications or choosing between truly *seamless* displays and those that contain frames.

Use or avoid Frames to control Distance

Also, frames can create distance between users of adjacent frames, especially if the display is curved convexly. For cooperation between users, frames are disadvantageous and a *seamless surface* should be used instead. On the other hand, whenever a greater distance between users is wanted (e.g. if applications require far-reaching gestures or more privacy between neighboring sections), frames can increase the distance. This distance may also influence social interaction between group members and control how groups disperse around a non-flat display.

Seamless Displays provide more Options

Finally, when choosing between a *polygonal* and a *seamless* non-flat display, the seamless display provides the option to also use frames. The *virtual frames* used in our experiment already worked well enough to accumulate users and draw them to the center position. In addition, *virtual frames* also allow a dynamic *moderation* of user positions over time. Thus, with a seamless non-flat display, designers will be more flexible regarding the use of *framedness*.

CONCLUSION

In this field study a completely round and seamless interactive column was installed in public and user behavior was analyzed in the wild. While previous work attributed certain user behavior such as positioning just to the *form* *factor* or to a single frame, we further separated out the factors *seamlessness* and *framedness*. Our experiment shows that by just switching on or off *framedness* on the same seamless display, user positioning around the column significantly changes. Just adding visual frames to the screen display was sufficient to keep users within the center area of the displayed frame. In addition to the form factor, also the framing of a display influences how people adjust in front of it, and each factor should be taken into account separately. This should be considered when planning more complex non-planar displays. Most interestingly, the results of the interviews reveal that users didn't recall the presence of the rectangular frames to which they aligned themselves.

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