Evaluation on Perceived Sizes Using Large-Scale Augmented Floor Visualization Devices

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ABSTRACT

Large scale output displays are an enabling technology in order to achieve immersive, isometrically registered, virtual environments. Amongst other benefits, pervasive displays allow for more accurate size judgments, better collaboration performance in workshops and less task completion time. Since research still does not offer an holistic view on size perception and reaction time using wall-sized displays, this paper follows a call for research. This evaluation investigates the size judgment accuracy, precision and reaction time using a large scale led floor compared to tablet computer with relative scales. Therefore, an output apparatus is presented using a 54 sqm LED floor surrounded by additional 36 square meters of LED walls. Using this apparatus, 22 participants were provided with the same virtual contents in 3 different scenarios. The baseline scenario (tablet computer) visualizes relative sized geometry, whereas two LED floor scenarios show true to scale (absolute sized) contents. Results indicate that using true to scale visualization of 2D contents on a LED floor reduces mean absolute percentage error (MAPE) of spatial estimations significantly and is the user's preferred visualization device. No systematic over- or underestimation of size judgments could be revealed for all three scenarios. In contrast to that, task completion time rises by using such an apparatus.

CCS CONCEPTS

• **Human-centered computing**; • **Visualization**; • **Empirical studies in visualization**;

KEYWORDS

true to scale visualization, size judgment, perception, led floor

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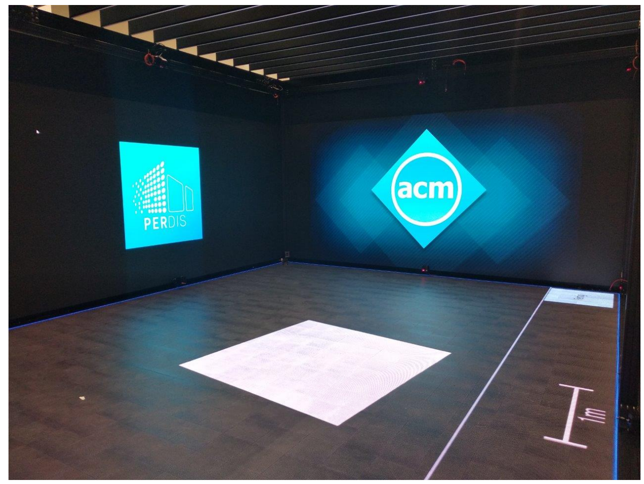

Figure 1: The apparatus consists of two L-arranged LED walls and a large scale LED floor setup.

1 INTRODUCTION

Wall-sized output devices are vastly used in design, manufacturing industry, entertainment and events for pervasive visualization of digital contents. Advances in display technology allow for high pixel density, therefore higher resolutions, bezel-less display clusters, 3D visualization, color fidelity and last but not least they are available at dropping prices. Nevertheless, human perception using this technology has not been in research focus extensively. Bezerianos et al. presentes a call for research[3] on the perception of data on wall-sized displays, since there is still little research carried out in this domain: "We do not yet know how the perceptual affordances of a wall, such as the wide viewing angles they cover, affect how data is perceived and comprehended". We follow this call for research and focus on 2D data visualization on large-scale LED floor displays showing contents in absolute scale.

1.1 Automotive Production Use Case

Presenting research on human spatial perception is not limited to this basic research interest, but is also carried out for a deeper understanding of a real-life use cases in manufacturing industry. The apparatus presented in the following is applied in automotive industry as an interactive, isometrically registered workshop environment. There, virtual assembly simulations are carried out in collaborative situations. The so called "Virtual Manufacturing

Table 1: Specifications of apparatus

Property	LED walls [each]	LED floor
Active Area	16 sqm	54 sqm
Pixel pitch	1.25 mm	5 mm
Resolution per wall	4800 x 2160	1728 x 1152
Size	6 m x 2.7 m	9 m x 6 m

Station" (VMS) is a XR framework for virtual assembly validations, which aim to optimize the product, process and resources within the future workplaces in manufacturing industry. It consists of large-scale displays and 3D tracking systems (see 1) and therefore allows to combine the advantages of physical and virtual validation by isometric registration and tracking of all components. Participants interactively optimize and validate these generated results [17].

Using the VMS, production validation engineers collaboratively evaluate and optimize existing planning data. Typical tasks are rearranging virtual workplace layouts, optimization of product assemblability, reduction of overall process time, optimization of ergonomic aspects and reduction of non-value adding tasks, such as walk paths (see [1, 16]. Literature often refers to this as "virtual continuous improvement process" [2]. One of the use cases is to display true to scale virtual content showing bird's eye view on virtual work place layouts. Typical examples for true to scale visualizations are displaying manufacturing station layouts or assessment of walk paths. For validation purposes, people have to estimate sizes as precisely and accurately as possible in order to judge the validity of planning data. Even when utilizing complex 3D models in combination with an orthographic, non-tracked virtual camera, visualization contents,such as racks and carriers are reduced to 2D squares. This is why, this perception study limits the focus on 2D square representations.

1.2 Specifications of the VMS

The VMS apparatus uses two identical LED walls arranged in a L-shape, closely attached with a large scale LED floor (see Figure 1). The specifications of LED walls and LED floor are shown in Table 1.

The LED floor contains proximity sensors for further applications such as walk path reconstruction. Additionally, the pixel pitch of 1.2 mm allows for 5k resolution on the powerwalls.

1.3 Size Perception

Using the LED floor in the above mentioned setup, raises the question on how people perceive sizes of virtual contents using pervasive displays with true to scale data visualization. Therefore, size judgment performance is compared between three scenarios, two of them showing to scale data representations on a LED floor and one showing relative-sized visualizations on a tablet computer. Analogously to the above mentioned use case, 2D representations are presented to the participants.

Nevertheless, using this technology human perception has not been in basic research focus extensively. Bezerianos et al. presented a call for research [3] on the perception of data on wall-sized displays, since there is still little research carried out in this domain: "We do not yet know how the perceptual affordances of a wall, such as the wide viewing angles they cover, affect how data is perceived and comprehended". We follow this call for research and add an additional element: Data visualization on large scale LED floor devices showing contents in absolute scale. The latter is structured as follows: First the state of the art in floor visualization devices and perception of true to scale visualizations is presented. Second, study goals, procedure and results are presented. With these insights on perceptual affordances, finally a discussion, summary and an outlook is given.

2 STATE OF THE ART

First, use cases of floor visualizations are summarized and second an overview on perception research is given for both real and virtual size estimations.

2.1 Use cases of Floor Visualization Systems

Besides already mentioned industry use cases, sports, gaming [10, 12], entertainment [7] and education [11] are using floor visualization systems vastly. Since use cases of this technology are highly heterogenous, only a couple of milestones are presented: In 1993 Cruz-Neira et al. used a "floor wall" projection system for presenting first a CAVE setup as the breakthrough for virtual reality (VR) applications [6]. For gaming purposes Gugenheimer et al. presented ShareVR [12] using an isometrically registered, floor projection setup for asymmetric visualization in collaborative environments, similarly to industry use case [17]. Lately, Ishii et al. presented a vision for enhancing the VR observer's experience by superimposing the visualizations of collaborative virtual environments in the so called ReverseCAVE [13].

2.2 True To Scale Perception and Size Judgment

Bezerianos et al. present a call for research [3] on wall-sized displays and call "for more studies on the perception of data on wall-sized displays". Using different types of output devices directly influence the spatial perception, visual space and the control of spatial behavior, especially when using display arrangements such as a LED floor.

In the pure physical domain, size and distance judgments have been in the focus of literature for a long time. In 1963 Epstein [8] presented the key findings, that distance and size judgments are not systematically related and deviations of size judgments varied with distance. Later, Epstein and Broota [9] presented a further evaluation on the judgment of sizes and distances and the corresponding reaction times. They found a positive correlation between viewing distance of objects and the reaction time. In Wagner's publication "The metric of visual space" [20], he gives insights on judging distances, angles and areas as conducted in this study. Cleveland and McGill present groundbreaking works in the visual decoding of information, namely graphical perception. They present a set of elementary perceptual tasks working and how people extract quantitative information[5]. More recently, Talbot et al. pick up these works and analyze the reasons for the differences in perception of charts [19].

For virtual environments, research focuses on perceived spaces in VR, such as distances, sizes, speeds and spaces. Loomis et al.

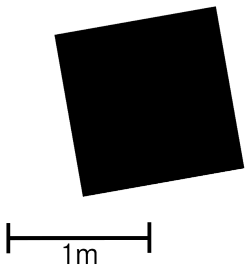

Figure 2: Visualized data: All 3 scenarios show a randomly scaled and rotated square in combination with a ruler as a visual cue.

showed that egocentric distance judgments in physical environments nearly match 100% of the actual distance [15], whereas in virtual environments they are often underestimated. Renner et al. presented a literature review and summarized that a "mean estimation of egocentric distances in virtual environments of about 74%" [18]. Renner et al. also clustered possible influence factors for this under perception of sizes in four different clusters: measurement methods, technical factors, compositional factors and human factors. In contrast, current state of the art head mounted displays seem to ameliorate these effects [14]. Kelly et al. showed, when using modern HMD devices, this effect is reduced but has not been completely resolved. In comparison with the literature, no relative size judgment has been carried out in VR by providing the user's with relative scales. In the latter, this study results are compared with literature findings on spatial perception. To the best of our knowledge, we are the first to execute size judgment experiments using a large scale LED floor setup in comparison to a small-size baseline measurement.

3 TRUE TO SCALE VISUALIZATION STUDY

One of the striking benefits of a large scale output devices is the possibility of visualizing true to scale data, contents or virtual scenes. In the context of the presented use case within the automotive industry, 3D contents with individual view points have been intentionally excluded, whereas 2D representations (see Figure 2) have been chosen for this study, since the aforementioned use cases are limited to data visualization of 2D data.

3.1 Study Goal and Predictions

This evaluation gives insights if people can assess sizes of 2D contents more accurately and precisely if they are shown in true to scale compared to relative-scaled representations. The baseline scenario represents relative-sized visualizations on a tablet computer, showing exactly the visual cues as in the true to scale scenarios. In this study, size judgment refers to the edge length estimations. To date, there is no published research documenting the extent to which true to scale floor content supports people in estimating sizes using augmented floor surfaces. To address these issues thoroughly, this study employs verbal distance judgments and objective measurements. Four different aspects are evaluated in this study:

- **Accuracy:** Is there a systematic over- or underestimation (accuracy) of size judgments? (Mean absolute percentage error)
- **Precision:** In which scenario participants achieve the most precise size judgments. (SD of mean absolute percentage error).
- **Task completion time:** Is there a difference in task completion time for the three different scenarios?
- **Qualitative feedback:** Are the user's subjective size judgments on precision and task completion time matching the objective measurements?

3.2 Participants

For this study 22 voluntary participants were randomly selected, such as production engineers, research engineers, PhD candidates and students from different production planning departments in manufacturing industry. 15 males and 7 females were taking part, all ranging from 21 to 57 years. (M=31.57, SD=11.52). All participants reported normal to corrected vision and chose the metric system as their preferred unit.

3.3 Setup, Stimuli and Design

Three different modes of perception are evaluated. For all three scenarios, the same visualization software, visual cues and interaction (besides user's movement) are used, only the output modality is changed (see Figure 3):

- **Tablet scenario (T):** Relative-sized visualizations as a baseline
- **Floor scenario (F):** True to scale visualization restricting user's viewpoint on the side of the LED floor
- **Floor and Interaction scenario (FI):** True to scale visualization allows user's movement on the whole LED floor

The rendering and evaluation software is a custom application which displays virtual squares in a randomized order (six different sequences for 3 scenarios) handling the randomized scenario work flow and logging the evaluation results (square size, square rotation, pixel per meter, scenario completion time). In all three scenarios the participants are shown 2D white squares on a black background. These squares have randomized sizes from 50 cm to 200 cm with random positions and orientations (+/-15°) on the screen (see Figure 2). Additionally, a virtual ruler represents the absolute length of one meter and remains at the same position (center bottom) throughout all scenarios. Besides the aforementioned 9 m x 6 m LED floor apparatus with 10.81 m screen diagonal for the scenarios (F) and (FI), scenario (T) is visualized on a 12,3" tablet screen, set to the same aspect ratio as the LED floor. The LED floor pixel pitch is 5 mm.

3.4 Procedure

After signing the informed consent, the participant is given verbal instructions on the goal and evaluation procedure. Each participant executes all three scenarios (T), (F) and (FI) (within-subject design) in a randomized order to abolish learning effects. There is no interaction with the virtual contents, so that the focus is limited to the differences in spatial perception. In each scenario 20 randomized (size, rotation, position) squares are visualized. After presenting

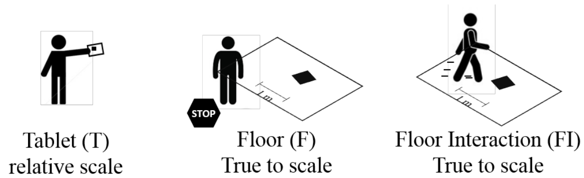

Figure 3: The three evaluation scenarios: (T), (F) and (FI)

each square, the participants verbally express their size estimate to the experimenter in the unit centimeters. The experimenter writes down the response for each estimation in parallel.

The three different scenarios are depicted in Figure 3 and described as follows:

- **Tablet (T):** The software visualizes the squares on the tablet computer as relatively sized content. The users have to judge the absolute edge length in relation to the visualized ruler.
- **Floor (F):** The software visualizes the squares on the LED floor to scale. The participant is directly facing the LED floor from a static location (compare [14]), standing on the outside border, centered on the long edge of the LED floor (3m to the center) and may not access it.
- **Floor&Interaction (FI):** Same setup as in scenario (F), but in contrast, he has the opportunity to move freely on the augmented floor during the study, so that the subject may position himself/herself directly above the respective square.

The experiment has been conducted a total of 22 times with different participants. Each evaluation takes approximately 20 min including the subsequent completion of the questionnaire. A total of 1320 datasets have been collected (22 participants, 3 scenarios, 20 trials) each one containing the actual & reported length [cm], spatial deviation/error [cm], task completion time [ms], pseudonym, scenario, square rotation and position.

Finally, participants are handed out and asked to fill out a questionnaire after execution of all three scenarios to gather their subjective feedback. They are asked about their personal scenario preferences for direct comparison. In addition, each subject is to select the method which he/she has preferred and specify the reason for his decision.

3.5 Results

The results are clustered in the three sections: Accuracy, precision and task completion time. Spatial discrepancy is the difference between the actual edge length (ground truth) of the squares and the estimation of each participant for the respective square edge length. Negative values represent an underestimation of size and vice versa.

Figure 4 shows an scatter plot of all three scenarios depicting the true length [cm] over the difference between true and estimated length. All three scenarios show, that in mean, there is only little overall over- or underestimation of the user's size judgments with (T) having a mean of 0.951 cm (SD=30.204), (F) −0.634 cm (SD=22.499) and (FI) −5.694 cm (SD=17.850). However, regarding the relatively large standard deviations compared to the small means, the interpretability of the aforementioned spatial discrepancy is disputable due to over- and underestimation. Furthermore, by tendency, the spatial discrepancy rise with growing edge length of the squares, especially considering (T) and (F). In order to normalize these effects, in the following the mean absolute percentage error (MAPE) and mean standard deviation (SD) of MAPE for trials within subject is used to evaluate accuracy and precision between all three scenarios.

3.5.1 Accuracy. MAPE is a measure of prediction accuracy.(T) shows a mean absolute percentage error of 14.783% (SD=5.612%), (F) 11.369% (SD=4.599%) and (FI) 9.814%(SD=3.957%). Figure 5 depicts the box plots of the MAPE of all three scenarios. A statistically comparison is conducted considering (T), (F) and (FI). Levene's test shows, that variance homogeneity is given for this data ($F(2,63)=0.942$, $p=0.395$), therefore the standard one-way ANOVA can be used in the latter. One-way ANOVA reports statistically significant difference between the three scenarios ($F(2,63) = 6.242$, $p = 0.003$). The post-hoc pairwise t-test with Holm correction reveals, that there is no significant difference between (FI) and (F) ($p=0.284$), but for both other scenarios (T) and (F) ($p=0.041$) and (T) and (FI) ($p=0.003$).

Overall, therefore the MAPE of both true to scale visualization scenarios (F) and (FI) can be regarded as significantly different from the relative scaled (T) scenario. As both mean MAPE values are lower, the scenarios (F) and (FI) have a higher accuracy compared to (T).

3.5.2 Precision. The mean SD of MAPE for trials within subject demonstrates the precision of size judgments represented by the "variance of absolute percentage errors". (T) shows a mean SD of 10.006% (SD=3.394%), (F) of 9.759% (SD=6.051%) and (FI) of 8.921% (SD=7.898%). Figure 6 depicts the SD of MAPE for trials within subject box plots of all three scenarios. Levene's test is utilized for testing equality of the variances in distributions. With $F(2,63)=0.329$, $p= 0.721$ it shows, that variance homogeneity is given for the SD. Therefore standard-one way ANOVA with post-hoc pairwise t-test with Holm correction can be used in this case which reports $F(2,63) = 0.184$, $p = 0.832$. Since one-way ANOVA shows no significance, post-hoc test results are not reported here.

No significant difference in precision can be found using true to scale visualization scenarios (F) and (FI) compared with (T). However, considering the descriptive statistics of mean SD of MAPE for trials within subject, a minor tendency of lower precision of (T) compared to (F) and (FI) is depicted (see Fig. 6).

3.5.3 Task Completion Time. The participants did neither get any instructions on task execution time nor on the priority between precision and speed. Nevertheless, task completion time has been tracked throughout the experiment. Time measurements have been gathered for every single size estimation in all scenarios, stating when a square is displayed and finishing when verbally passing the size judgment to the study manager.

Participants show a training curve throughout the 20 runs of each scenario. All in all, run 2 to 20, the median of scenario (T) is 5.063 ms, whereas the scenarios (FI) (9.959 ms) and (F) (8.429 ms) are slower. For all three scenarios the very first runs show a higher median values (see Figure 7) caused by non-existing training.

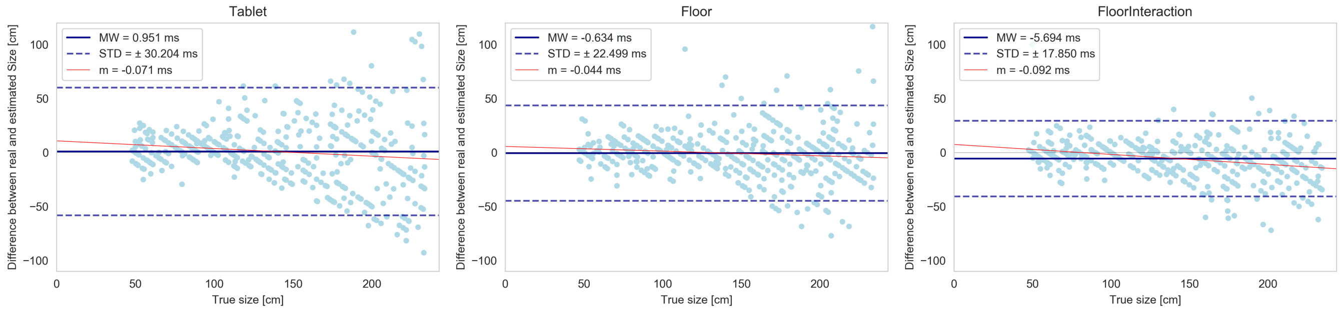

Figure 4: Scatter plot of absolute spatial deviations to true length for all 3 scenarios (following Bland-Altman plot [4])

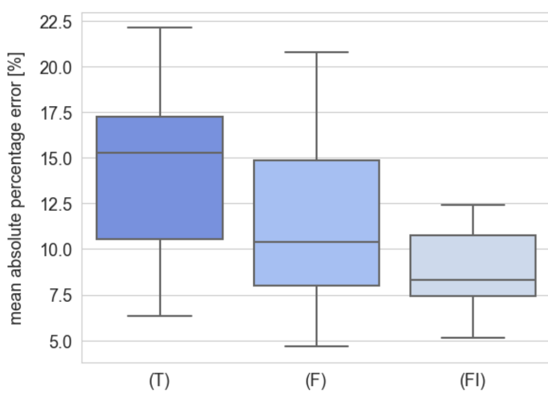

Figure 5: Box plot for MAPE of scenarios (T), (F) and (FI)

3.6 Questionnaire Results

After having performed the experiment, all 22 participants filled out a questionnaire on their subjective perception. In the following the objective metrics are compared to their subjective perception of the participants.

Table 2: Comparison of median task completion times

Scenario	Median of first run [s]	Median of run 2 - 20 [s]
Tablet (T)	10.84	5.06
Floor (F)	9.90	8.43
Floor&Interaction (FI)	16.23	9.96

3.6.1 Task Completion Time: "For this method, I was able to judge the sizes more quickly". The participants had to decide on each possible pairwise combination of all three scenarios: "(T) or (FI)", "(T) or (F)", "(F) or (FI)". Overall, the subjectively fastest scenario is (T). Comparing the scenarios (F) and (FI) the results are equal (50% vs. 50%). Comparing both floor scenarios (F) and (FI) to the (T) scenario a subjective time benefit of (T) is reported 72.73% in favor of (T) compared to (FI) and 63% in favor of (T) compared to (F). The subjective questionnaire feedback matches the objectively measured times. 86.67% of the participants were really quicker, when they are in favor of the (T) scenario in terms of task completion time. In contrast to that, only 7.14% of people in favor of (F) or (FI) scenarios were really quicker.

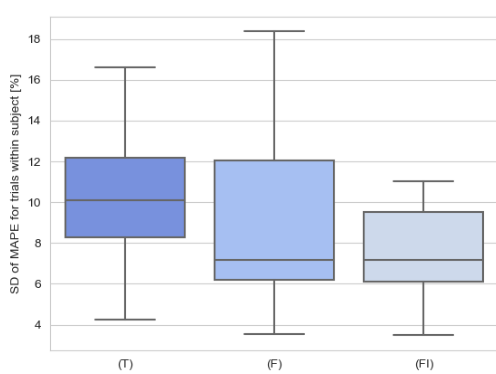

Figure 6: Box plot for SD of unsigned percentage errors in scenarios (T), (F) and (FI)

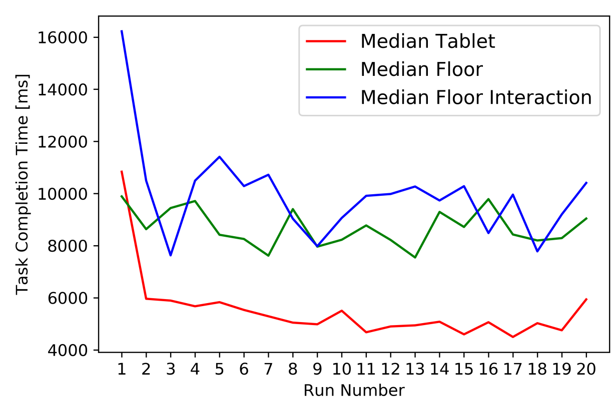

Figure 7: Median task completion time of all participants (N=22) for all 3 scenarios throughout the 20 runs

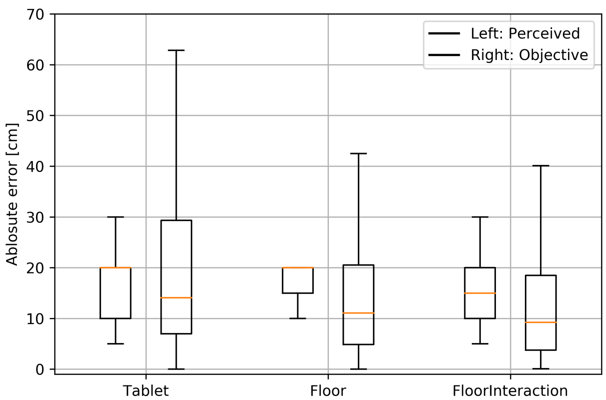

Figure 8: Comparison between perceived absolute error and objective absolute error. N=22 for each scenario.

3.6.2 Precision: "Using this scenario, I'm able to assess the sizes more precisely". As for task completion time all pairwise combinations of scenarios are tested: (FI) is estimated the most precise scenario (46.97%) followed by (T) (31.82%) and (F) (21.21%). Interestingly, people clearly preferred (FI) over (F) (86.36%), whereas when comparing (FI) to (T) and (F) to (T) there is no clear preference (50.00% and 54.55% in favor of both floor scenarios). Comparing those subjective results with objective error metrics, there is a false impression for the subject's error estimation capability using (T) scenario. Only 28.57% objectively performed more precisely using (T) even though they are estimating this scenario as the most precise one. In contrast 78.26% of people who are in favor of either (F) or (FI) scenarios also objectively performed better using these scenarios. Additionally participants reported on their absolute subjective size judgment error. In general, participants objectively performed better with a lower absolute median error than they subjectively expected it to be (positive values only).(see Figure 8). For (T) scenario the perceived median absolute error is 20.00 cm, whereas objective median error is 14.08 cm. The same holds for (F) (perceived 20.00 cm, objective 11.08 cm) and (FI) (perceived 15.00 cm, objective 9.25 cm)

3.6.3 Personal Preference: "I personally prefer the following scenario": The highest ranked scenario is (FI) with 59.09%, followed by (T) (31.82%) and (F) (9.09%). Despite (T) is ranked second as a preferred scenario, participants who preferred this scenario never performed best (0/7) best in terms of precision and most of them even performed the worst (5/7). Additionally, the questionnaire gathered free answer possibilities: The participants reported, that when using (FI) they felt "more confident estimating sizes" (3x), "used natural walking" (1x) to estimate the absolute lengths and to change their "viewing perspective" (2x) so that the squares are "right in front of them" (1x). They report to get a better "spatial sense" (1x) and realism degree (2x). Additionally such a true to scale visualization is helpful. People who prefer the (T) scenario subjectively mentioned a better "overview" (3x) and better "comparison with ruler" (2x) due to the smaller display size and "higher resolution" (1x).

3.7 Discussion

This study shows, that absolute (true to scale) and relative visualizations both have differing advantages: On the one hand, without changing the type of interaction and just by changing the output, there is a significant change in size judgment accuracy between tablet and both floor scenarios (F) and (FI). So using the LED floor with true to scale visualization has a positive influence on the precision perception of sizes. These experimental results are in accordance with earlier findings by Otto et al. [17]. In contrast to other state of the art papers evaluating perceived spaces in VR [14], this study does not show over- or under estimation. Therefore using true to scale visualization enable the participants to judge sizes more accurately.

On the other hand, the objective task completion times indicate, that using (F) and (FI) in general is slower than using (T). Even though, lower task completion times could be a hindrance factor for other use cases, in automotive production validation task completion time is less important than a high accuracy.

Each participant reports size judgments in a rounded form: Typical reports of size estimation granularity are 5 cm (5/22), 10 cm (16/22) and 25 cm (1/22) steps. None of the participants gave subcentimeter precision results. Therefore, rounding effects are still smaller than the perceived size judgment capability (compare Figure 8).

4 CONCLUSION

This paper presents a novel collaborative virtual environment for virtual production validation and gives insights on using different modes of perception, namely true to scale (absolute) and relative scale visualizations. Size judgment accuracy is better using an absolute visualization scenario (F) and (FI) whereas task completion time rises using those scenarios compared to the baseline scenario (T). In comparison with VR spatial estimations, where sizes are oftentimes underestimated, for true to scale floor visualizations, no generalizable deviations could be revealed. Various use cases depend on reliable spatial estimations of humans, such as collaborative production validation workshops. The presented apparatus consists of an 54 sqm LED floor with a 5 mm pixel pitch and proofed to be a helpful tool for visualization of virtual true to scale contents.

5 OUTLOOK

Future research will focus on interaction in isometrically, co-located virtual environments. For this purpose, true to scale visualizations both on the LED floor and LED walls are an enabling technology. Additionally, using the presented apparatus, further interaction research will be carried out, since it offers the possibility of foot step recognition. Such a reconstruction of human walk paths can be used to partly replace complex motion capture systems.

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