Impact of Manikin Display on Perception of Spatial Planning

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Impact of Manikin Display on Perception of Spatial Planning

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ABSTRACT

The visualization of spaces, both virtual and built, has long been an important part of the environment design process. Industry tools to visualize occupancy have grown from simple drop-in stock photos post-design to real-time crowds simulations. However, while treatment of visualization and collaborative design processes has long been discussed in the HCI and Architecture communities, these inclusive design methods are infrequently seen in architecture education (e.g. studio) and practice, nor implemented in licensure requirements – leaving designers to think about the future occupants on their own. While there are strong indicators of the impact visualization modality and rendering style have on perception of scale and space, little has been explored regarding how we represent the human form with respect to these design tools and practices. We present findings from a novel online interactive space planning and estimation study that examines the effects of 3 common building visualization modalities in the design process with 3 human form modalities extracted from the architecture literature. Results indicate the type of visualization changes the number of occupants estimated, and that designers prefer integrated manikins within building models when estimating space usage, although their acceptance was equally divided between 2D and 3D. Our findings lay the foundation for new and focused design tools integrating human form and factors at building scale.

CCS CONCEPTS

• **Applied computing** → **Computer-aided design**; **Psychology**; • **Human-centered computing** → HCI design and evaluation methods; • **Computing methodologies** → **Perception**.

KEYWORDS

human factors, architectural design, visualization

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1 INTRODUCTION

As part of the Architectural licensing requirements, designers are trained and tested on developing a *program* for a space. This program is an estimation for the occupancy various spaces will have when a building is in operation, and it takes on a vital role in determining the needs of future users. Often this program is developed through a simple spreadsheet, where the area of each room and the number of rooms are balanced against the needs/wants of building owners. From a long tradition of blueprints and two-dimensional visualization techniques (*e.g.*, section and plan), designers continue to plan spaces using flat representations of what an environment looks like, which are often in the form of orthographic slices. Although designers have clearly adopted three-dimensional visualizations and largely embraced *Computer-Aided Design* (CAD) tools, there is seemingly a resistance to adopting three dimensions for many of the planning needs, as educational curricula, architecture licensure exams, and legal documents– require the use of 2D representations (*e.g.*, floorplans).

While past and recent studies have explored the role of *Virtual Reality* (VR) in the design process (*e.g.*, [Zhang et al. 2020]) for futuristic design processes, there are unfortunately fewer studies exploring how to improve *current* building design processes. The best illustration of this rests in the required Architecture License exam and professional degree curriculum in which 3D visualization – let alone VR – is not described as a mode of building design and communication. Rather, architects are required to learn, and are tested on their ability, to understand and create 2D floorplans. There are many possible, and valid reasons for requiring such standardized modes of visualization. Amongst conversations with architects, an often cited rationale for such a situation is the ability to *quickly* see and understand the space, with an architect's job (and training) being the ability to mentally translate between 2D representations into their 3D counterparts. However, the impact such a practice has on a designer's consideration and thought of how future occupants may use the space – and specifically the space needed for human

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occupants to comfortably experience the environment – has yet to be studied in detail.

As a precursor to our research, we discussed the role human factors have in the design and planning process with experts at university campus planning and regional infrastructure (*e.g.*, airports). Of particular note was a general and consistent lack of simulation and consideration of low-level human factors. In a discussion with a university campus planner, there was a note that human factors have rarely (if ever) been discussed when deciding on project proposals. However, this expert explained that with the recent pandemic, planning required a shift in thinking to consider lower-level space functions such as social distancing, and with this, came a discussion in more nuanced requirements of the space that will continue beyond the current situation.

Many of the studies relating to human manikins and visualization modes in design, in particular within HCI, are focused on what is often considered human-scale, or the scale of ergonomics (*e.g.*, chair, table, etc.). In these instances, the relationship between multiple occupants, the ability for occupants to *move in and out* while still being considered *part of the design space* is uniquely absent and requires separate study. More recently there has been additional research into VR at the room scale [Gagnon et al. 2021a]. Although we expect the architecture and interior design fields to incorporate more VR within their design process, it is (1) unlikely to be completely changed in the immediate future and (2) necessary to understand how the use of human manikins influences design processes in existing tools before assuming their enhanced utility in immersive tools as well.

Following this line of reasoning, our work is framed by a few key questions that inform our experimental design, namely:

- (**R1**) Does the mode of representing occupants (and the corresponding presentation mode of the environment) impact the perception of how many occupants could comfortably fit? If so, does this differ between designers and general public?
- (**R2**) Does domain expertise of the building in question change how someone estimates occupancy?
- (**R3**) Do designers find that 3D manikins facilitate space planning estimates?

In this paper, we answer these questions with a novel human avatar visualization platform that replicates the design visualization modalities of the most common building design tools. We can visualize humans in many ways, allowing an exploration of the interactions between design and human visualizations, such as the human manikin used in architecture and design training (a human reference designers will be accustomed to). The results of our experiments point toward a promising direction in human visualization but that the impact of how we choose to represent humans is much more complicated.

2 BACKGROUND AND RELATED WORK

Although both *Human Computer Interaction* (HCI) and Psychometrics are well established and have a vast literature on virtual environments relating to perception and scale, there is a lack of literature that has focused such efforts directly on the built environment **design process**. Likewise, while interfaces and tools are thoroughly explored in the Design field, the focus is often on the improvements made to a designers own workflow. Due to the end-goal of the design process, the influence of a human has implications not only for scale, but for the projected assumptions in how others would use and perform in a space (*e.g.*, the impact of avatar on empathy and compassion).

2.1 Perception of Scale and Place

Understanding perceived spatial cues and distance estimation in new modes of visualization is an ongoing topic in HCI. Scale and spatial cues in VR is uniquely different than design tools, which are expected to have clear annotations and interactivity for understanding scale. Past studies have found nonlinear distance estimations in VR (using *Head Mounted Display* (HMD)) with a mixed egocentric and exocentric perspective through midpoint estimation [Bodenheimer et al. 2007]. Recent studies in *Augmented Reality* (AR) found underestimation of distances in AR occurred more strongly in open rooms, likely due to stronger linear perspective cues in hallways [Gagnon et al. 2021b]. Past research has also shown the importance of human body and segment scale for accurate perception of ability and scale of virtual environments [Jun et al. 2015]. Recently, it was shown that distance compression affects perception of actual lengths but not relative length judgement tasks for data visualizations in VR. In VR, amplification of movements for a users' avatar showed a tendency to overestimate distance (greater in width than height) [Kokkinara et al. 2015]. In the architecture domain, [Aseeri et al. 2019] studied HMD-based VR estimates of distance judgments, finding no evidence that adding a virtual human at different sizes would help as virtual rulers.

These studies, while identifying pertinent challenges to human perception, assume an immersion of the user (*i.e.*, egocentric measurements), while architecture and interior design rarely use such techniques during the design process. While 3D modeling is commonplace, architectural education and licensure remains heavily focused on two-dimensional views and diagrams (*e.g.*, floorplans). More similarly to our work, a study in comparing 2D views using blueprints with videos of simulated walkthroughs provided correlations to ground-truth measures of visual perception only to the video-based mode [Hölscher and Dalton 2008].

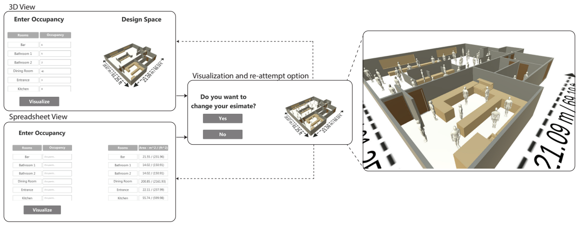
In addition to studies of scale, human representation is an ongoing research topic in itself. The uncanny valley is of interest not just for viewers comfort, but for emotions and considerations one may attribute to such virtual humans [Mori et al. 2012]. For example, a viewer's assessment of virtual characters' *charisma* was found to be higher in less realistic characters [Araujo et al. 2021]. While there may be reasons outside the scope of our work, it raises the question of how representation modes may lead to other perceived characteristics, and how these attributed characteristics or connections may impact the way one considers the environmental context/situation. In an extensive study and review of Anthropographics, little evidence was found that visualization designed with such techniques provide significant changes with respect to their decisions [Morais et al. 2021]. This may have implications on the use of manikins that are provided as a visualization where the motivation is to promote prosocial behaviour by encouraging a balance between maximizing occupancy for profit (*i.e.*, turnover in a restaurant) and improving occupant comfort. Likewise, if the *granularity* or *specificity* of the visualization does not influence one’s perception of how people would be impacted (*e.g.*, by projecting discomfort from overcrowdedness), such efforts in including human representations may be equal to a measuring stick. Research has found that rendering style did not effect the illusion of presence with virtual characters increased fidelity [Zibrek et al. 2019], more charisma was perceived in unrealistic characters [Araujo et al. 2021], and cylinders were not significantly different than humanoid characters on physiological response when approaching in VR [Llobera et al. 2010].

2.2 Digital Humans in Environment Design

Research into integration of human tasks as an evaluation method in floorplan design tools has existed since at least the 1980’s [Lantrip 1986], but is far more developed in engineering fields (*e.g.*, Technomatix Jack [Blanchonette 2010; Phillips and Badler 1988]), with a long history in industrial operations engineering, transportation design, and at the product design scale [Lee et al. 2019]. More recently (with few exceptions), researchers, and the tools themselves, have largely focused efforts on the analysis of digital models, rather than the integration as a design aid, such as the case for automatic code checking [Eastman et al. 2009] (which *e.g.*, includes accessibility code). In a recent review, it was found that there is a common use of the terms agent/avatar within *Architecture Engineering and Construction* (AEC), but also pointed out that these were often byproducts of other investigations and the implementation of virtual humans is still immature for AEC [Eiris and Gheisari 2017].

While crowd-based simulations exist in the literature, the ubiquity within design practice is somewhat limited due to difficulty in the integration of the design process. Moreover, only a few recent works show interactive crowd simulation as a *design tool* [Chakraborty et al. 2017; Haworth et al. 2017; Usman et al. 2018]. In industry, crowd-specific tools are used [Bentley [n.d.]; Oasys [n.d.]; PDS Parametric Design Studio [n.d.]; PTV Group [n.d.]; SAVANNAH SIMULATIONS AG [n.d.]; The AnyLogic Company [n.d.]], but these focus on formal evaluation such as egress towards the end of a design process, and not necessarily for perception of occupancy (although it is possible to use as such). Multi-agent simulators have been proposed as environment evaluation tools [Chu et al. 2014; Goldstein et al. 2010; Pan et al. 2007; Schaumann et al. 2017; Yan and Kalay 2004]. However, common amongst the HCI literature is an evaluative approach with respect to a tool created and its ability to reduce a specific metric, such as time, when used. Our work aims to help build the foundational set of studies necessary to support implications of these (and future) works.

Recently, [Obeidat and Jaradat 2022] studied how first-year design students’ opinion of spatial qualities changes in a specific environment when various human avatars are included. Their work is tangential to ours in that the study condition does not resemble design programs, mixes realistic people with unrealistic rooms, and is studying how the inclusion of more people changes a students view of the space (rather than the student determining how many people would fit within the space). In one of the few studies specific to human avatars and the design process, the impact of using a virtual avatar had on creative exploration was explored using novel solutions to follies (*i.e.*, ornate structure) as the proposed mechanism [Hong et al. 2019]. It is difficult, however, to interpret the results of what is considered *creative solutions*, with the authors acknowledging the need for additional studies focused on the avatars. Social facilitation is another aspect to consider when introducing virtual humans. While the literature is focused on the introduction of virtual avatars’ effect on accuracy and duration of simple vs. complex tasks, such social influence or awareness may have an impact [Zanbaka et al. 2007]. With Revit, Autocad, and Rhino 3D being among the most popular tools for architectural and interior design – it is notable that none of these tools come *standard* with virtual manikins – especially not ones that are integrated in the design planning and conceptualization process. There are third-party plugins and tools that can help facilitate these manikins, and often rendering tools such as Enscape [GmbH 2022] can be used with manikins to help visualize the space utilization. However, this is typically done post-design and the primary focus is to bring environment designs to life.



Rooms	Area - m^2 / (ft^2)
Bar	21.55 / (231.96)
Bathroom 1	14.02 / (150.91)
Bathroom 2	14.02 / (150.91)
Dining Room	200.85 / (2161.93)
Entrance	22.11 / (237.99)
Kitchen	55.74 / (599.98)

Figure 1: Here, two of the seven representation modes used in the interactive study, *3D* and *Spreadsheet*, are used to illustrate our study process. After each screen, a visualization of human manikins populating the space is provided. Participants may repeat this process and adjust their occupancy estimate using the same representation.

3 EXPERIMENTAL METHODS

3.1 Overview

We develop an online and *interactive* spatial planning apparatus that lets users navigate in 2D and/or 3D space to explore a randomized set of restaurant environment models to help them in estimating occupancy. Our apparatus records users estimates, the number of trials, and time taken per condition. A conceptual overview of this process is provided in Figure 1, although the full view of each condition includes a navigation panel (discussed in §3.3). The apparatus is implemented with webGL, and was accessed (and conducted) within the browser by redirecting subjects to a URL after completing a preliminary survey.

3.2 Participants

Our study was reviewed by an IRB before initiation. Owing to the openness and applicability of the built environment to all people, the inclusion criteria was a minimum age of 18 years. Participants were recruited via email using lists which specifically included trained and licensed designers as well as general population. Recipients were asked to share amongst their peers to facilitate a snowball sampling strategy. We recruited 192 participants to our initial demographics survey (implemented in Qualtrics), however only 105 of them completed all portions of the study. We removed participants that submitted less than 7 occupants for the total final estimate of the rooms combined (a nonsensical one person per room). We had 2 participants estimate over 1000 occupants in their initial estimate. These subjects were removed, as their entry for that one condition was deemed an error. Our final group consists of 84 participants (designers $n = 24$, non-designers $n = 60$). Participants were asked to provide educational, design, and workplace experience. Of our sample we had ($n = 20$) participants with restaurant experience.

For restaurant experience we ask, "How many years of experience do you have in the restaurant industry?" For design, we ask participants how many years of experience in design they have. Next (for >0 years), we ask if they are currently licensed as an architect or interior designer. If not, we followup asking if they are currently working towards licensure, and if not, whether their state has a license option. This latter part is due to the fact that, while Architecture is nearly ubiquitously a professional program with licensure, interior design is not always a licensed profession. While design is a large field containing many types of people and applications, we focus on designers that work at the building scale. As both interior designers and architects qualify in this category, we refer to this grouping simply as *designers*, and all other participants in our study as *non-designers* (referring to building users). However, it is possible (and likely) some participants may be designers in another area (*e.g.*, industrial design) but classified as non-designer. Such categorization is short-hand for building designer, throughout our paper. After completing the inclusion criteria and demographics questionnaire, participants are redirected to our interactive platform.

3.3 Stimuli and Design

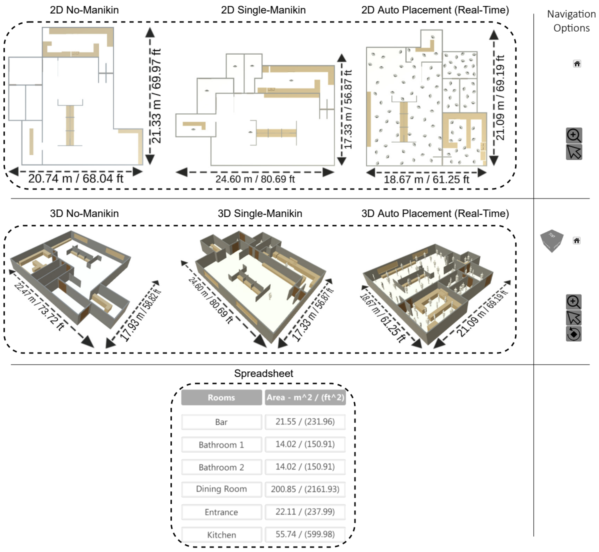


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Figure 2: The main visualization modes: tabular program, 2D and 3D. The 2D and 3D modes also have: (1) a single manikin per room and (2) an automatically placed population of the user-entered occupancy (in real-time). Interactive navigation options are shown on the right.

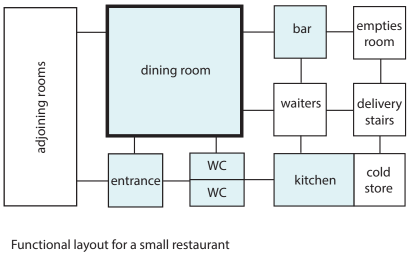

Figure 3: Functional diagram of a small restaurant, as shown in [Neufert and Neufert 2000]. Light blue indicates rooms used in this study.

We developed and deployed a novel interactive platform to enable participants to explore digital building models and their occupancy with two varying properties: (1) the visualization modality of the building (2) the visualization modality of the human manikin. Modalities of this interface are shown in Figure 2. We primarily wished to investigate representations in the design views building designers are most commonly working in. We replicate important view and navigation components of the user interface found in the software Autodesk Revit ®. The ViewCube [Khan et al. 2008] is one of the most distinct and permeated features of this design software. We implemented a subset of the interactivity the ViewCube offers while constraining the orientation to aid those not familiar with exploring and navigating a 3D environment (to avoid getting stuck in poor visibility orientations). In this study, design view is an independent variable constructed from the following combinations: (1) tabular program (a table view for occupancy commonly used to design building use programs); (2) 2D blueprint view (an orthographic projection from the top principal view, with panning and zoom); (3) 3D building model (full ViewCube use with additional pan, zoom, and constrained rotation controls). Similarly, within these modalities, humans can either be present or not and visualized by: (1) textual information (occupancy counts); (2) 2D human manikin; and (3) 3D human manikin.

The human manikins were created based on a commonly used design book in architecture training [Panero and Zelnik 1979]. The 2D manikin was recreated directly from a top view provided in the book, while the 3D manikin was modeled by combining a front and right principal orthographic views (seen in Appendix A.1).

Together, the building and human visualization modalities combined form the experimental conditions for our study. In particular, we wished to explore and control the differences between no use of human representation, use of a singular static human representation for each room occupancy, and use of real-time updated room occupancy. For the single static human representation, we place one manikin in a central location in each room. For the real-time updated room occupancy, we use a modified Poisson disk sampling (with randomized rotations) to procedurally place the desired number of manikin in each room. This sampling ensures that the visualized manikin are uniformly distributed in the floor area of the room. In total, this produces 7 conditions for our study: Tabular program, 2D blueprint with no mannequins, 2D blueprint with singular mannequins, 2D blueprint with mannequins updated in real-time, 3D model with no mannequins, 3D model with singular mannequins, and 3D model with mannequins updated in real-time.

In this study, we wished to control for learning effects in several ways. To ensure that participants results are comparable but also to avoid visualizing the same building model across modalities, we generated a functional layout from which unique designs were constructed. The building models (7) are of a restaurant environment modeled based on the spatial planning relationships defined by [Neufert and Neufert 2000] (Figure 3). The same rooms across the 7 models have the same room area, with only the shape changing. Each model also varies general locations of the rooms but maintains the spatial relationships defined in the functional layout (see Appendix A.1). We use the regularly occupied subset of these rooms from the original functional layout to generate our own designs. We highlight the rooms used in blue in the recreated functional diagram in Figure 3. Each building model in our study contains: Bar; (x2) Bathrooms; Dining Room; Entryway; Kitchen.

3.4 Procedure

After being redirected from the demographic survey, subjects are prompted to start the occupancy estimation portion. In the first available screen, instructions were provided as open captions to an animated video explaining the study interface and procedure, including the available navigation controls and screen layout. The video was 120 seconds long and would repeat automatically. Participants were required to press a "Ready" button to begin the study, which was deactivated until the first play through of the video finished. Participants were instructed to fill out occupancy tables for the rooms that will be presented based on a balance of comfort and maximum occupancy. They are asked to revise their estimates until satisfactory in as few iterations as necessary.

After the instructional video, participants are delivered the 7 experimental conditions in a randomized order. Each condition (except for the tabular program) is randomly assigned one of the 7 available building models derived from the functional design in Figure 3. This ensures that all participants see all conditions in a fully randomized order with randomized stimuli for our within-subjects experimental design. During each condition, the participant may enter their occupancy estimation for each room into an occupancy table interface (see Figure 2). For the real-time manikin conditions, changing values in these text fields automatically changes the visualization on the right (Figure 1, right). As instructed in the video, when a participant is finished entering occupancy numbers they may press the next button. At this point, participants are shown the distributed manikins, in the same manner as the 3D real-time updated manikins condition, and asked if they wish to modify their answer. If they choose to modify their answer by pressing the "Yes" button, they are returned to the condition interface and may revise their inputs. If they choose to continue by pressing the "No" button, they are asked a simple math question in the form of a CAPTCHA. The inclusion of this step is meant to create a separator between the conditions, ideally helping further control for learning effects and to keep participants from simply clicking through the study and entering the same values repeatedly. This process repeats until all conditions have been seen. During this portion of the study we record the total time spent on each condition variant (referred to as a trial), the time per generated estimate (trial), and the number of estimates per trial (the number of iterations the participant makes for a particular condition). At the end of the study, participants are asked a question with Likert-type responses in grid format for both 2D and 3D, *"Would you use manikins in your design process if they were well integrated into the tools you use?"* The responses were coded as (5) "Extremely Likely", (4) "Likely", (3) "Neutral", (2) "Unlikely", (1) "Extremely Unlikely".

Immediately following these, participants were presented with questions to help understand the usefulness of manikin visualization with respect to each other. We code our questions for later reference, provided here in bold:

(UQ1) *Did you find the use of a 2D manikin easier to estimate the number of people you thought would use the space than the floorplan without a manikin?*
(UQ2) *Did you find the use of a 3D manikin easier to estimate the number of people you thought would use the space than the 2D representations?*
(UQ3) *Did you find the use of the 3D manikin easier to estimate the number of people you thought would use the space than the empty 3D representations?*
(UQ4) *Do you currently use 2D manikins placed inside of your space when designing?*
(UQ5) *Do you currently use 3D manikins placed inside of your space when designing?*

Questions were provided as a multiple choice with "Yes"/"No" options on the first three questions, with "N/A" options additionally provided for questions that were only related to Designers (*e.g.*, "Do you currently use 2D manikins placed inside of your space when designing?").

4 ANALYSIS AND RESULTS

Our data processing was performed in Python 3.8 and statistical analysis was performed in R [R Core Team 2022]. Normality checks were verified by QQ plots and Levene's test for Homogeneity of Variance was carried out. We conducted separate individual multi-way univariate analysis of variance (ANOVA), one for each of the methods to interpret the spatial planning process. We use this method instead of a multivariate analysis as the dependent variables of interest are being considered independently (*e.g.*, how long the process takes vs. the number of occupants estimated) [Huberty and Morris 1992]. For brevity in figures and tables, we code the conditions as: (**A**← 2D), (**B**← 3D), (**C**← Spreadsheet), (**M**← Includes one Manikin per room), (**RT**← Realtime Manikin Display).

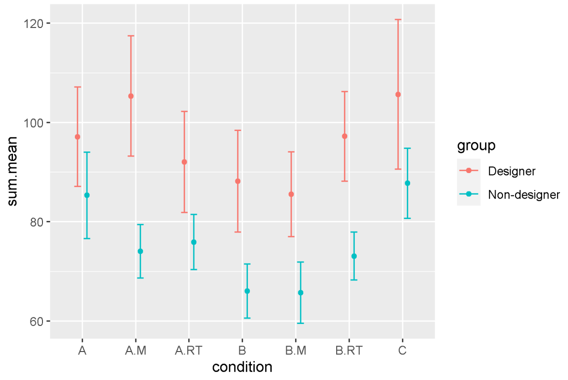

Figure 4: Mean of the first estimate by Designers and Non-designers.

We consolidate the six room estimates by aggregating the data of all rooms together (*i.e.*, sum of all room estimates per condition).

The mean estimate for each group on the *first* attempt of each condition is shown with standard error bars in Figure 4. Mean values show designers have a higher estimate across all conditions than the other group. As an additional reference point, the dining area, as described in our designers reference ([Neufert and Neufert 2000]), suggests a seating occupancy of 110, and with 15 sq. ft. per person, a maximum legal occupancy would be roughly 144.

Table 1: Summary statistics of difference between first and final estimate. Values only include subjects in which they clicked the option to change their estimate. *n* column shows number of subjects included.

condition	group	n	mean	sd
A	Designer	11.00	-13.18	24.19
A	Non-designer	25.00	7.04	55.09
A.M	Designer	9.00	-10.44	24.43
A.M	Non-designer	24.00	-8.12	22.63
A.RT	Designer	9.00	-14.89	36.70
A.RT	Non-designer	19.00	-2.89	25.34
B	Designer	13.00	-10.92	54.15
B	Non-designer	31.00	-9.32	14.73
B.M	Designer	9.00	-11.22	18.08
B.M	Non-designer	26.00	-8.35	29.12
C	Designer	9.00	-7.78	51.46
C	Non-designer	29.00	7.21	28.02

To understand if the initial visualization mode has an impact on a subject's estimate compared to populated 3D view, we report the difference in number of occupants estimated of the first trial to the submitted trial in Table 1. As this table reports the difference in first and final estimates, it does not include data from subjects in which they did not change their estimate (*i.e.*, did not choose to go back and modify their answer after seeing the 3D condition). The *n* value shown in this table represents the number of subjects that had changed their answer. Notably, this table lacks the `B.RT` (3D realtime) condition, as this mode populates the model with the same ending visualization as the other rounds, and therefore has only one estimate (no difference to report). In all cases, designers reduced their estimate after seeing the 3D environment populated with 3D manikins. This average reduction is seen in all other conditions except for Non-designers in the 2D view (without manikin) and spreadsheet view.

Subjects were allowed to change their estimate as many times as desired. Figure 5 visualizes the number of revisions by condition. For Non-designers, the majority of subjects changed their estimate once or twice, with the spreadsheet and 2D view without manikins re-estimated by a subject 5 and 6 times, respectively. However for Designers, a few subjects modified their estimates multiple times in the 3D view without manikin (`B`).

A multi-way ANOVA was performed to measure main effects and interaction of the experience and display conditions on the initial estimate for room occupancy. We found a significant main effect of the group factor ($(F(1, 560) = 19.58, p < 0.0001)$) and a strong trend on condition ($(F(6, 560) = 2.029, p = 0.06)$). There was no interaction found between group:experience ($(F(1, 560) = 0.35, p = 0.55)$), group:condition ($(F(6, 560) = 0.26, p = 9.55)$), experience:condition ($(F(6, 560) = 0.124, p = 0.993)$), and group:experience:condition ($(F(6, 560) = 0.0579, p = 0.9992)$).

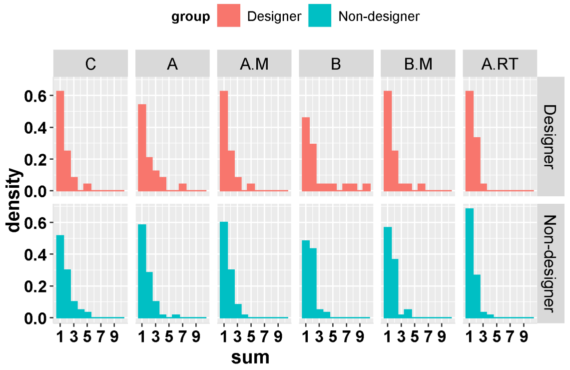

Figure 5: Density plot of the number of estimates, with values higher than 1 representing additional changes to the estimate.

To further understand the trend seen in the main effect of condition, a paired t-test was performed within each group using a Bonferroni adjustment to the p-value. The following results report the *higher* mean estimate in bold. There was only one pair of conditions found to be significantly different for the Designer group (**A.M**:B.M, $p.adj = 0.019$). For Non-designers, there was a significant difference in the estimates between the 3D and spreadsheet views (B:**C**, $p.adj = 0.001$), (B.M:**C**, $p.adj = 0.024$), (B.RT:**C**, $p.adj = 0.024$), and the empty 2D and 3D modes (**A**:B, $p.adj = 0.035$). A slight trend was seen between the 2D with single manikin and 3D empty modes (**A.M**:B, $p.adj = 0.084$). The summary of first estimates can be seen in Appendix A.3.

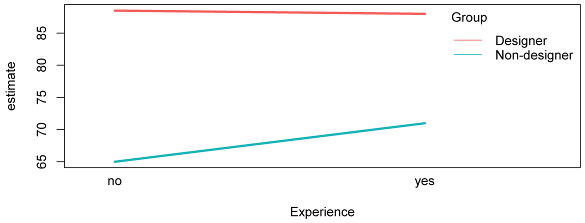

Figure 6: Interaction plot of experience in the restaurant industry for Designers and Non-designers.

A multi-way ANOVA was performed to measure main effects and interaction on the last estimate for room occupancy. We found a significant main effect of the group factor ($F(1, 560) = 32.8, p < 0.0001$) and a slight trend on the interaction between group:experience ($F(6, 560) = 2.905, p = 0.0889$). The interaction plot for this is shown in Figure 6. There was no main effect found on condition ($F(6, 560) = 1.4252, p = 0.2026$) nor experience ($F(1, 560) = 0.1451, p = 0.7034$). The interactions between group:condition, experience:condition, group:experience:condition all had an F value ≈ 0.15 and p-value > 0.95.

Finally, we performed a multi-way ANOVA on the total time spent per condition, finding a strong trend of the main effect of group ($F(1, 560) = 3.5356, p = 0.0606$). No other effect or interaction was found to be significant.

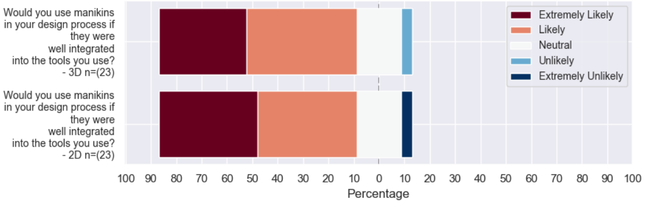

Figure 7: Responses by designers on willingness to use manikins in their design process. (Top) response to 3D manikin. (Bottom) response to 2D manikin.

In the likert-style response (Figure 7), 78% (n=18) of respondents stated they are either Likely or Extremely Likely to use either 2D or 3D manikins in their design process. The same number of participants in 2D and 3D cases were neutral, while one participant answered *Unlikely* to 3D manikins and one participants answered *Extremely Unlikely* for 2D manikins.

The results of our representation-dependent ease-of-use questionnaire are shown in Figure 8a. In these plots, we show three groups, however, the Non-designer and Designer groups are independent, while the third Restaurant group is a combination of the former represented by those with experience. When asked if the 2D manikin made estimating occupancy easier than just a floorplan view (**UQ1**), all groups were strongly in positive agreement. This remained true for the related question (**UQ3**), if the 3D manikin was easier to use than an empty room. Of note is the unique response of the design group to our question comparing 3D to 2D (**UQ2**). While all groups responses suggest the difference between a manikin (2D or 3D) is better than no manikin, the 3D manikin was not always better than the 2D manikin. In fact, the design group stated "No" (n=12) to the 3D manikin being easier than the 2D manikin equally frequent as "Yes" (n=12).

When asked if they currently use 2D and/or 3D manikins in their design process, our design respondents reported yes (n=9) and no (n=12) for their use of 2D manikins in their current design process, and the slight majority (n=11, n=10) stated they do not use 3D manikins (Figure 8b).

5 DISCUSSION

The findings pose a few important points to reflect on when discussing how we design tools and programs for not only professional designers, but non-designers that may be involved in a collaborative design practice. First, the initial response was significantly effected by the condition being displayed to a subject. In particular, non-designers estimated *higher* numbers of occupants in conditions that had the least amount of information (*i.e.*, a spreadsheet view and an empty 2D view). Designers had a similar trend for these conditions but was not found to be significant. We modeled the spreadsheet view off the U.S. Architectural exam and industry practice for space planning, and the 2D view is a standard floorplan. As the fully populated 3D condition shown at the end of each condition is visually (and navigation) identical to the real-time 3D condition, the initial estimate for this condition being most similar to the 2D with single manikin and real-time 2D conditions is noteworthy. These finding may have implications for how collaborations between designers and their clients use visualization tools as the mode itself may lead someone to over or under estimate the comfortable number of people that can occupy a space. Our study diverges from much of the literature in design perception as we focus on processes and methods directly related to current design practice, rather than distance estimates using HMD.

When considering the number of subjects that changed their response after seeing the populated 3D view, it is interesting to note that for both designers and Non-designers, the highest number of changes occurred after the empty 3D view ($n = 13, n = 31$ respectively). This was unexpected, as it has the same perspective and model. A possible explanation could be the difficulty in understanding the scale of a room with respect to room objects without people. Such reasoning could be further studied as it would strongly suggest the need for more universally adopted tools that contain 3D manikins.

The mean difference between first and last estimates was generally larger for the Designer group. Additionally, the slight trend ($p \approx 0.09$) of the interaction between groups and restaurant experience showed that Non-designers with experience estimated slightly higher. One reason for these results could be the roles each of these groups have experienced – Designers often consider occupancy in terms of what is maximally allowed, restaurant workers understand what is balanced between comfort and maximal occupancy, and non-designers without experience prefer less crowding. However, further studies with these roles in mind would be needed to confirm.

Amongst the likert-style questions at the end of our perceptual study there was agreement across the groups and experienced users, with the exception of the 3D vs. 2D modes. The designer group was split between thinking the 3D mode was easier than the 2D mode to estimate occupancy. While these direct-responses to perceived ease of use are valuable for understanding design tool adoption and integration with design processes, it is worth comparing to the time spent, as the average time for the 3D mode (B) was lower slightly lower for the Design group compared to the 2D mode (A). We therefore infer from our results that the ease of use perceived by a designer, and their preference for one mode over another, may not be represented in studies that solely look at the speed to converge at a solution or the accuracy in estimation. Additionally, designers may simply prefer representation modes they have been trained on.

A limitation of our study with respect to total time taken is the lack of user interface tracking. While Designers were likely comfortable with the 3D navigation tool as it was mimicked from Revit, Non-designers may have spent extra time. Alternatively, some subjects may not have used the navigation tools at all, which would conflate the time taken due to thinking about an estimate and the time taken for navigation. However, as our study apparatus is a replication of the interfaces used by designers, these general results are realistic.

While research in HCI and interactive design tools, both in 3D and in VR, continues to develop– our findings emphasize a need for great caution and recognition with the way building-scale designers

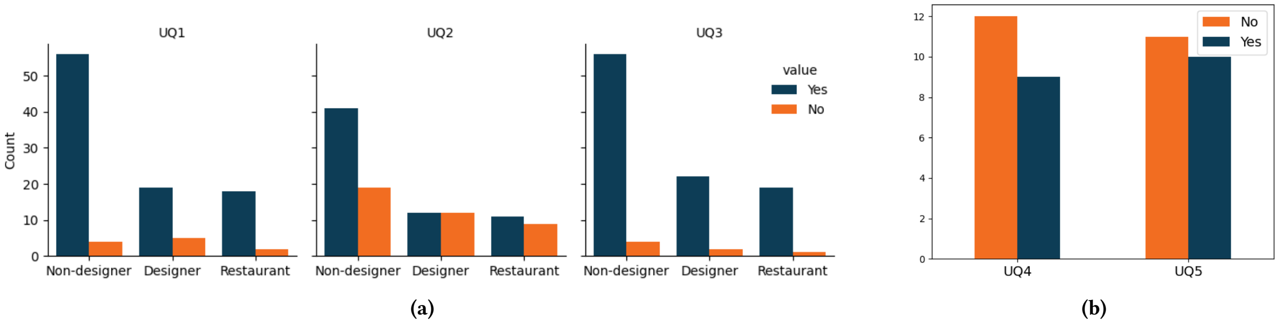

Figure 8: (a) Responses by the three groups (Designer, Non-designer, and restaurant experience) to the three questions on the ease of use between the 2D and 3D modes with/without manikins and the 2D vs 3D manikin (UQ1, UQ2, UQ3, as detailed in List 3.4). (b) Yes/No responses by designers to questions UQ4 and UQ5, as detailed in List 3.4).

currently work (and are educated). On the other hand, we see this disconnect between the comfort level of designers with 2D representations as a strong avenue for future research, specifically of more complex perceptions designers (and users) may have of a space whereby the comfort with 2D representations is superseded by the importance of the changed perception in the alternative mode (*e.g.*, if non-2D representations increase empathy for building occupants and acknowledgement of accessibility-related issues).

One way to consider human manikins in large-scale environmental design tools is a type of Anthropographic. While *Digital Human Models* (DHM)s, especially in the industrial design scale, are useful for understanding specific anthropometric relationships between the human and product, as well as fine-grained interaction, most architecture design processes consider a much coarser view that considers complex relationships between many elements–including the designers' own aesthetic and conceptual desire. By looking at an empty building, one could consider the size as a spatial facilitation of desired tasks, and the inclusion of manikins to be a visualization of the people connected to it (*i.e.*, occupants), where we consider it to have *maximum granularity*, low *specificity*, and moderate *realism* (see [Morais et al. 2021] for context). In the literature, terms like Avatar, Agent, Virtual Human, etc. are all used to describe the integration of people in virtual building environments, yet the implications of how these modes work with respect to a *manikin* existing in the design space is still unknown.

We also find it noteworthy how many participants currently use 3D manikins in their design process. As discussed in § 2, while there exist plugins that supplement manikins in design tools, we are unaware of any architectural design-specific software that currently contains human manikins by default (*e.g.*, Revit [Autodesk [n.d.]c], Rhino 3D [Associates [n.d.]], Autocad [Autodesk [n.d.]b]) with the exception of 3D Studio Max [Autodesk [n.d.]a] that contains a biped for character animation. We assume most participants using Revit or SketchUp have Enscape, which allows the manual placement of realistic humans in specific poses. Participants may also have conflated images of humans that can be superimposed into a 3D space with that of fully 3D manikins. Further studies are warranted on what these tools are, and at what stage(s) of the design process they are used, as this software is typically used and advertised for realistic visualization (compared to early stage design support).

6 CONCLUSION

In this paper, a novel apparatus was used to study the perceptual effect of human manikins visualized in a space on a subject's estimation for how many people would comfortably fit within that space. An analysis was performed between a design group consisting of either licensed in architectural/interior design or working towards their license and a non-design group. An additional factor was considered for their experience in the restaurant industry, as our realistic scenario followed industry standard rules on design layout and size of restaurants. We find that the mode of visualization and representation of human manikins had a significant impact on the number of occupants estimated for a space, in particular for Non-designers, and experience in the restaurant had a slight trend of interaction with Non-designers to estimate higher. We followed our interactive study with survey questions for both groups. In summary, participants were in general agreement that the inclusion of a 2D manikin and a 3D manikin is easier to estimate occupancy than just an empty floorplan or 3D model. While Non-designers mostly agreed the inclusion of a 3D manikin was helpful, the Design group was split, with half disagreeing that a 3D manikin was easier to estimate occupancy than a 2D version. Our results have significant implications for the future design of design tools and interfaces for helping large scale (building) design process, a much understudied topic in HCI when compared to the design of products (*i.e.*, industrial design) and software applications (*e.g.*, smartphone apps).

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A APPENDIX

A.1 Procedure and Stimuli

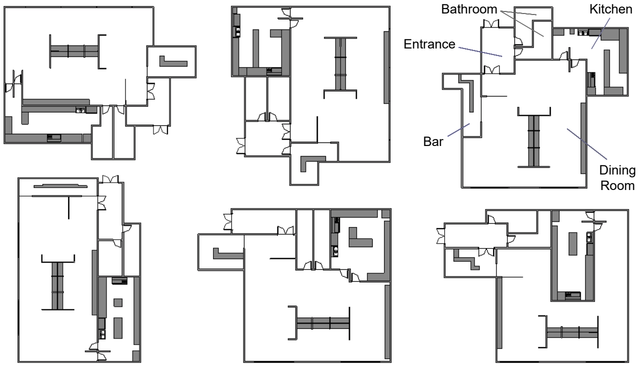

Figure 9: Examples of the restaurant designs used in the study, each with matching room areas shown as 2d floorplans as output from Architectural design software.

We developed multiple floorplans that contain equal area in each room, as well as being connected with the same functional diagram. Examples of these environments are shown in Figure 9.

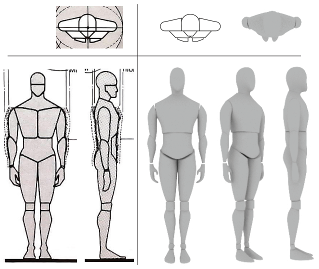

Figure 10: (left of bar) Human representations from [Panero and Zelnik 1979] and (right of bar) the reconstructed manikins used in our study. (top of bars) the 2D and top-down view of the manikins.

Rather than using scanned people are artistically generated/realistic humans, we retraced the human manikin outline provided by a well established design handbook. Additionally, to properly compare this manikin within a 3D context, we utilized the multiple views of the handbooks manikin to make a generic 3D model. We show the different views of our model in Figure 10.

A.2 Time

The time per condition was recorded for all participants. This time (in seconds) often has a large variation, with the standard deviation shown in Table 11.

In Figure 11, a plot of the total time per condition is shown, with mean represented as a dot and standard error for the measurements. Notably, the standard error from the mean for Designers is much larger than Non-designers (which could be an effect from a smaller population and/or higher standard deviations).

Table 2: Summary statistics of total time per condition, including when users changed their estimate.

condition	group	n	mean	sd
A	Designer	24.0000	63.8932	55.3039
A	Non-designer	60.0000	64.1276	66.5645
A.M	Designer	24.0000	99.7862	165.2078
A.M	Non-designer	60.0000	52.9130	36.2487
A.RT	Designer	24.0000	70.3973	44.0134
A.RT	Non-designer	60.0000	80.7699	66.0083
B	Designer	24.0000	95.6435	135.5288
B	Non-designer	60.0000	68.7905	60.3561
B.M	Designer	24.0000	55.5777	27.6354
B.M	Non-designer	60.0000	73.6873	62.1537
B.RT	Designer	24.0000	98.9330	79.0112
B.RT	Non-designer	60.0000	84.4964	67.1233
C	Designer	24.0000	109.4569	168.5542
C	Non-designer	60.0000	74.6119	61.4283

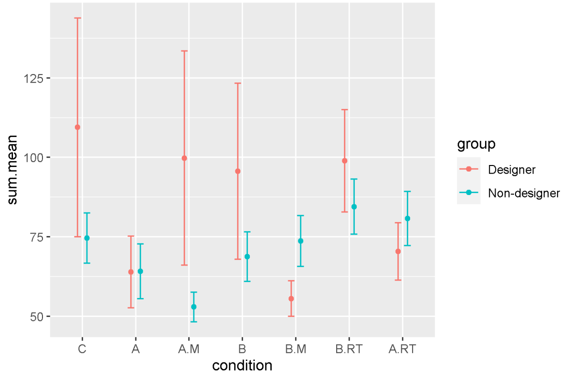

Figure 11: Total time per condition.

A.3 Estimates

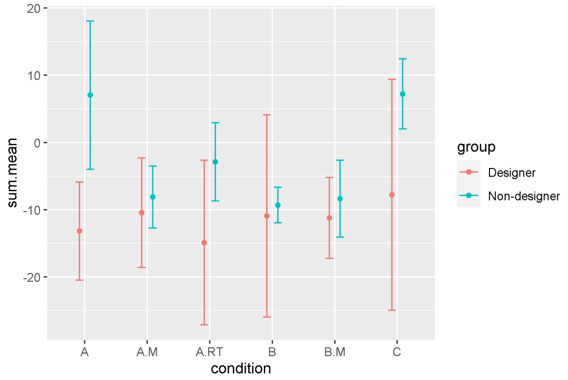

Figure 12: Difference between first and last estimate.

In Figure 12 we show a plot of the difference between first and last estimates for each group.

Table 3: Summary statistics of first estimate

condition	group	n	mean	sd
A	Designer	24.00	97.12	49.06
A	Non-designer	60.00	85.32	67.35
A.M	Designer	24.00	105.33	59.33
A.M	Non-designer	60.00	74.05	41.90
A.RT	Designer	24.00	92.04	49.82
A.RT	Non-designer	60.00	75.90	43.00
B	Designer	24.00	88.17	50.23
B	Non-designer	60.00	66.03	42.12
B.M	Designer	24.00	85.54	41.93
B.M	Non-designer	60.00	65.72	47.96
B.RT	Designer	24.00	97.21	44.23
B.RT	Non-designer	60.00	73.07	37.41
C	Designer	24.00	105.67	73.91
C	Non-designer	60.00	87.75	54.53

The summary statistics for the first estimate are provided in Table 3.