INFORMED DESIGN OF PEDESTRIAN PATHWAYS

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Abstract. Development of the Singaporean transport network has been fairly utilitarian in design and much can still be done to enhance pedestrian comfort. This research aims to better understand the preferences of pedestrians in Singapore with respect to different factors that influence comfort. Based on the many frameworks for assessing pedestrian perception of urban design qualities, a digital preference survey was created and conducted with 300 participants. From the results of the survey, several design recommendations were drawn. Following this, a parametric model was developed to create prototypes of various recommended designs and to aid further studies in the form of a virtual reality experiment.

Keywords. Pedestrian Comfort, Transit Oriented Walkways, Evidence Based Design, User Centred Design, VR.

1. Introduction

Across the world, cities are developing transit oriented development (TOD) policies by advocating high dense urban developments around public transport nodes, creating mixed-use areas with pedestrian- and cycling-friendly environments (Calthorpe 1993, Cervero 2009). While TOD was originally confined to North American scholarly debates, global application of its principles has greatly expanded the initial organisation framework and typology. In Singapore, the Land Transport Master Plan (LTMP) 2030, which was released in 2013, paved the way for the integration of pedestrian-oriented mobility ideas as the first and last mile solutions into the urban transport network.

The public transport system in Singapore is divided into three branches; the MRT (Mass Rapid Transit), LRT (Light Rail Transit), and buses, which were designed to

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cater for different scales of commute, where commuting patterns are primarily influenced by distance and travel time from housing to education/employment, rather than shopping (Shimazaki et al. 1994). The current transport infrastructure was designed largely based on safety, passenger loading, and more recently incorporated universal design. The development of Singapore's transport network over the past decades has been largely driven by the utilitarian objective of catering to the needs of its burgeoning population. Pedestrian comfort, in the context of Singapore, still has a large potential to be explored for a better commuting experience.

The research presented in this paper focuses on the behavioural understanding and necessary tools and recommendations for enhancing existing and designing new comfortable and functional transit oriented pedestrian walkways in Singapore. The main premise of this study is that users' perception of comfort in pedestrian walkways considerably depends on their design qualities and the crowd conditions. Therefore the main objective of this study is to capture what design factors and design features for pedestrian walkways influence comfort and functionality during peak uses and how.

Section 2 of this paper outlines the conceptual framework employed in this study. Sections 3 and 4 describe the framework, including the research method, survey instrument development, and analysis. Sections 5 and 6 outline and discuss the main findings gained from survey data analysis, and suggest some design recommendations. Finally, section 7 concludes the paper.

2. Literature Review - Towards Theoretical Framework

Pedestrian perception of urban design qualities is a well-researched topic. There are numerous "classic" frameworks available for capturing, assessing and explaining the properties of urban environments that shape users' spatial perception, use, comfort, and behaviour (see e.g., Appleyard 1981, Cullen 1961, Gehl 1996, Hillier 1996, Jacobs 1961, Jacobs 1995, Lynch 1960, Whyte 1988). Among the more recent such frameworks, Carmona et al. (2010) proposed six critical dimensions of urban spaces, namely: morphological, perceptual, social, visual, functional and temporal dimension. Another framework by Cho et al. (2015, 2016) described three components of urban space quality: design properties (hardware), use and socio-perceptual values (software), and management and operational conditions (orgware), whereby hardware comprises seven critical attributes, including: "accessibility, connectivity, mobility means, legibility and edges (porosity), spatial variety, environmentally friendly design strategies, and user comfort" (Cho et al. 2015, p.153). According to Ewing and Clemente (2013), there are 51 perceptual qualities of the built environment, among which eight are described as the most important ones, namely: "imageability, enclosure, human scale, transparency, complexity, coherence, legibility and linkage" (Ewing and Clemente 2013, p.4).

Within the context of pedestrian comfort, our framework focuses on enclosure, sense of comfort, legibility, linkage and complexity as important parameters in the design of pedestrian walkways (Figure 1).

Enclosure refers to the degree a space is visually (and physically) defined by vertical elements, such as walls, tall greenery, or ceiling (Ewing and Clemente 2013). According to Jacobs (1993), great streets have well-defined boundaries. For Gehl

(1996), such boundaries need to be active, both in terms of visual, sensorial (textures, colours, materials), and activity rhythms (entrances, transparent façade and adjacent uses), in order to create joyful walking experience.

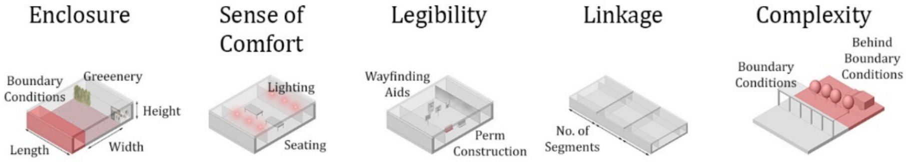

Figure 1. Selected perceptual qualities of the built environment for the conceptual framework for pedestrian comfort and some of their selected spatial parameters.

Sense of comfort is a cumulative effect of a range of environmental, aesthetic, social, and psychological factors, such as micro-climate and lighting conditions or provision of seating amenities and restorative design features (Carmona et al. 2010, Cho et al. 2016). These may be critical for walking experience in the tropical climate of Singapore. Sense of comfort is also tightly related to human scale of a built environment. Gehl (2010) emphasised the importance of 'human dimension' and the qualities of urban environments at the 'eye level' for social vitality of public space, whereby personal space considers the distance of 45cm-1.2m, social sphere - 1.2-3.7m, and public realm - beyond 3.7m. The social field of vision of 100m with a 25m threshold enables pedestrians to effectively watch people and register facial expressions. Jacobs (1961) also wrote about sidewalks as being points of social contact, with safety being critical in its consumption.

Legibility refers to scale and visual understanding of the spatial structure and is crucial for wayfinding. Lynch describes it as "the ease with which its [environment's] parts can be recognized and can be organized into a coherent pattern" (Lynch 1960, pp.2-3). Permeability of edges is one of the key elements of a legible built environment (Carmona et al. 2010). Legibility of a place is improved when there is an orderly recognisable pattern of streets, plazas, and other macro-scale elements as well as coherence in the micro-scale elements of façade, landscaping, street furniture, paving materials, and signage. Imageability, on the other hand, is "that quality in a physical object which gives high probability of evoking a strong image in any given observer" (Lynch 1960, p.9). It is related to a "sense of place", whereby characteristic physical features can contribute to a cohesive image of a place (Cullen 1961).

Linkage refers to physical and visual connections from building to street, building to building, space to space, or one side of the street to the other. Linkage is related to connectivity and accessibility (ease of movement in an area and relationships between paths, nodes, and edges) and may be present in the form of a physically connected link, an implied link, built-in link, etc. (Maki 1964).

Complexity is defined by a spatial diversity of visual, experiential, and functional information provided in an urban setting (Marcus and Francis 1997). Pedestrians are most comfortable receiving information at perceivable moderate rates (Berlyne 1971, Kaplan and Kaplan, 1989). While too much information leads to sensory overload, too little, on the other hand, creates a uniform and boring walking experience. Visual richness of a built environment can be qualified/quantified with the following aspects:

layering at the edge of streets, from sidewalk to arcade to courtyard to building, diversity of building ages and architectural elements, diversity of social settings, diversity of uses/activities over the course of a day, and signage. Complexity has also been measured by the changes in texture, width, height, and setback of buildings.

3. Research Methods

The research is carried out in 2 parts. The first part consists of a digital preference survey to methodologically value selected design parameters in indoor and outdoor pedestrian pathways in Singapore, in crowded and non-crowded conditions. We identified measures (design parameters) for each of the qualities described in the framework and compared them to each other by using images created and manipulated in Adobe Photoshop to depict each design parameter. Width, division, edge conditions, lighting conditions, visibility, floor material, ceiling material, shelter conditions, and obstructions were the selected design parameters (Figure 2).

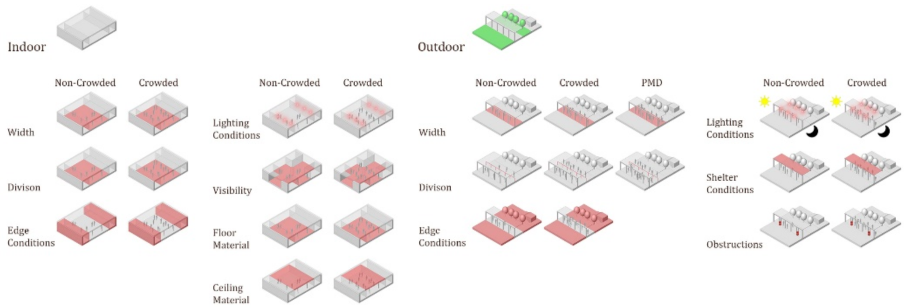

Figure 2. Design parameters embedded and tested in the preference survey.

The second part is a Virtual Reality (VR) experiment. Based on the results from the survey, we selected 8 different edge conditions that may affect how comfortable people feel in a space. Using a parametric model, these conditions were modelled as segments of a straight corridor, textured, and populated with agents in Unity. During the experiments, eye tracking and appreciation data were collected.

3.1. SURVEY

The survey was conducted on 300 participants whose age and ethnicity demographics represented the generic population distribution of Singapore with an added emphasis on people with children using strollers, wheelchair users and their caregivers, as categorized under special requirements.

211 unique images were created in Photoshop according to the various categories of the selected design parameters. Each category contained a set of images where only a single parameter was varied at a time. The main objective of this was to cover a wide spectrum of physical attributes in the built environment and to explore undiscovered trends in relation to pedestrian comfort.

The survey was carried out digitally. Each question presented respondents with two images with the prompt: “As part of your daily commute, imagine you are walking through this path. Which path do you prefer to be included as part of your daily commute?". Respondents clicked on one of the two images to proceed to the next question.

The images compared in the survey were divided into 7 indoor and 6 outdoor categories, representing the measures of selected design parameters (Figure 2). For each comparison, there was 1 variant for non-crowded conditions and 1 for crowded conditions. Some categories also had a third variant, for the presence of personal mobility devices (PMDs).

The full survey consisted of 430 of such questions. It was split evenly into 3 separate surveys of 143 to 144 questions each in order to reduce fatigue, after determining that the ideal length for the survey comprised 100-150 questions completed in 15 to 20 minutes. The questions were assigned to each subset such that each survey link contained an evenly spread amount of questions in each category, with no repeating scenarios. In order to further reduce the impact of fatigue, short scenic videos of nature were added at constant intervals as breaks.

The order of questions was randomized in order to mitigate the impact of fatigue on the results and to eliminate learning order effects. The positioning of the images on the left and right were also randomized to alleviate the "one-sided clicking phenomena", which may be a result of boredom or pure disregard for the objectives of the survey.

During the process of creating the final survey, two pilot tests were carried out to collect feedback on question and image clarity and survey length. The images went through several rounds of iteration for maximum clarity for the respondent to spot the differences in the images upon first glance. These changes include adjusting contrast, manipulating size and positions of objects, and removing redundant images in which differences were not significant to the respondents.

3.2. VIRTUAL REALITY EXPERIMENT

VR, which is three-dimensional in nature, allows for certain environmental attributes to be experimented with (Figure 3) as these attributes cannot be simply tested through static images. Each participant walks through a virtual path of the eight indoor environments placed in a linear manner with breaks in-between each environment. The order of placement for each environment was randomized to eliminate order learning effects.

4. Survey Analysis Methodology

Data collected through the survey (retrieved in CSV format, filtered and imported into a MySQL database) was analysed according to several key aspects, including: individual preferences and amount of time spent per response, demographics (age, gender), crowding conditions, and indoor vs outdoor (Figure 3). The images were further grouped and analyzed according to their intrinsic features in order to identify sets of logics applied in the respondents' preferences. The results from the survey were also aggregated based on various hypotheses and Chi-Square tests were done on the aggregated data to determine if there were any correlations between some of the design parameters and/or demographic factors.

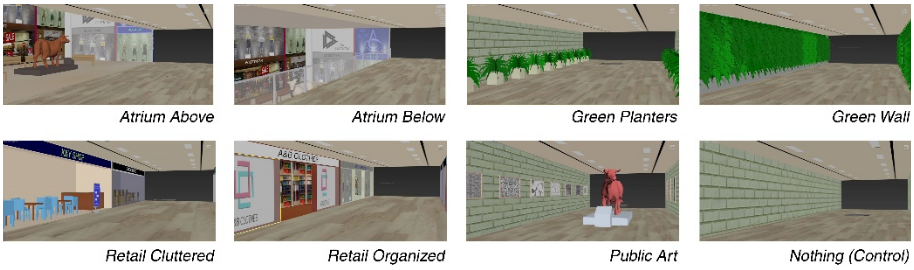

Figure 3. The eight design variants presented to participants in the VR experiment.

5. Survey Results

The main findings as outlined in Figure 4 can be summarised as follows:

Width		Wide	Tapering (Inverse Y)	Tapering (Y-shaped)	Normal	Narrow		
		74.00	68.75	51.25	45.50	4.00		
Division		No Barrier	Seating	Arrows on Floor	Planters	Arrows on Ceiling	2 Floor Textures	Handrail
		78.00	64.50	56.30	49.20	49.10	49.10	30.25
Edge Condition		Curtain Wall	Commercial no Queue	Commercial with Queue	Seating	Blank Wall		
		76.13	64.63	56.88	38.25	14.13		
Visibility	Path Type	4 Point Cross	Curved	3 Point T-Junction	Straight	Straight with stairs		
		56.00	54.88	53.50	47.75	37.88		
	Path Condition	Sky	Normal	Double height	Obstruction			
		68.17	59.20	49.03	23.60			
Lighting	Brightness	High	Normal	Low				
		64.50	51.75	33.75				
	Colour	Normal	Warm	Cool				
		58.75	62.25	29.00				
Floor	Material	Marble	Timber	Carpet	Concrete Imprint	Grass		
		70.50	68.50	56.50	37.13	17.38		
	Colour	Light	Dark					
		72.00	28.00					
Ceiling	Material	Plaster	Timber	Concrete Imprint				
		70.50	55.25	24.25				
	Colour	Light	Dark					
		81.50	18.50					

Width		Wider	Normal	Narrow			
		74.10	47.90	28.00			
Division		No Barrier	Arrows on Floor	2 Floor Textures	Seating	Planters	Barrier
		74.33	61.83	52.08	50.08	48.58	35.07
Edge Condition	Features	Open street	Cycling path	Plants (Sparse)	Seating	Empty Road	Shops
		73.50	71.00	63.55	61.36	55.23	52.27
		Motorcycle	Carpark	Parked Cars	Plants (Dense)	Truck with Exhaust	Retaining wall
		51.64	49.82	42.86	34.45	31.14	13.18
	Number of Lanes	Three lanes	One lane				
		50.50	49.50				
Lighting Condition		Night with Bright Lights	Day	Night with Dim Lights			
		72.00	70.25	7.75			
Shelter Condition		Permanent Shelter	Glass Shelter	Trellis	Temporary Shelter		
		58.00	54.17	50.33	37.50		
Obstructions		Dustbins	Parked Bicycles	Bus Stop			
		67.25	40.25	42.50			

Figure 4. Rankings by category - indoor condition (left) and outdoor condition (right).

Width. People prefer wider pathways in all conditions (Figure 5 left), especially male and older participants. There is a stronger preference for wider paths in indoor conditions, potentially due to visual openness of the outdoor pathways. Respondents with special requirements tend to be more tolerant of narrow width as compared to those with no special requirements. This could be because people are obliged to give way to those with special requirements. Finally, people have less obvious preferences regarding walkway widths for elevated links.

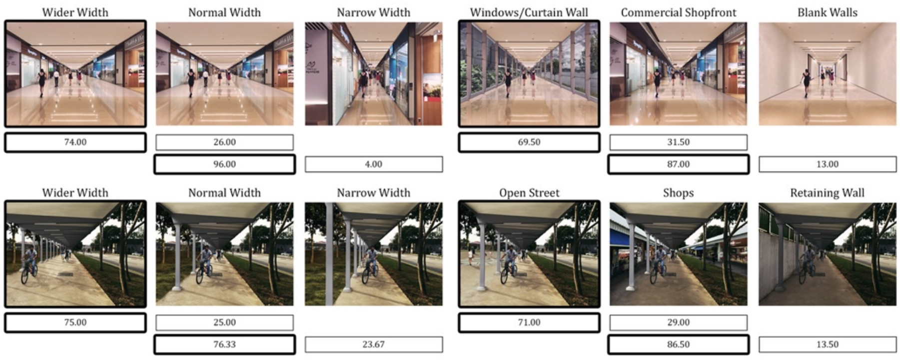

Figure 4. Walkway widths in indoor and outdoor conditions (left 3 columns); edge conditions of indoor and outdoor walkways (right 3 columns).

Division. In outdoor walkways, people prefer when there is a clear separation between PMDs/cyclists path and pedestrian path. In indoor environment, people prefer when there is no barrier to direct flow of pedestrian traffic. In non-crowded conditions, function of the barriers is more important - people prefer physical barriers with additional function. In crowded conditions, size of the barriers matters, with people leaning towards smaller physical barriers (Figure 6 left).

Edge conditions. People prefer open edge conditions that provide a connection to the outdoors/surroundings more than enclosure or other functionality like shopping or seats (figure 5 right). In the interior, transparently designed structures (e.g. surfaces) may create a visual expansion, thus leading to a more bearable situation for pedestrians. Crowding has little impact on the pedestrian's perception of urban design elements that suggests the availability of space through enclosure or transparency. Females prefer seating (at the edge) more than males in non-crowded conditions.

Figure 6. Physical barriers under non-crowded (left 2 columns) and crowded (next 2 columns) conditions in indoor and outdoor walkways; lighting conditions under non-crowded (next 2 columns)

and crowded (right 2 columns) conditions in indoor and outdoor walkways.

Visibility. There is a preference for 3-point and 4-point junctions over straight junctions. A curved path is more preferred than a straight one.

Lighting. People generally prefer brighter lighting in all conditions (more notably in outdoor condition), especially female (in non-crowded condition) and older participants, arguably due to perceived safety (Figure 6 right).

Obstructions. In crowded condition, people prefer smaller physical obstructions (i.e., dustbins).

Ceiling and floor. Overall, lighter and smoother surfaces are more preferred than darker and rougher ones for both ceilings and floors. Male participants prefer sky compared to everything else more than female participants. Respondents with special requirements prefer sky over other path conditions more than respondents with no special requirements.

Shelter condition. In outdoor environment, people dislike temporary shelters (often near construction sites), but prefer more permanent ones whether opaque or transparent (glass or trellises).

Overall, in the context of Singapore, outdoor spaces do not necessarily fair better than indoor spaces when there is a high density of people/crowd.

6. Design Recommendations

We recommend designing paths that are wider where possible, with edge conditions that are more open. Where this is not possible, we recommend including some elements like seating or planters. Such open edge conditions could be in the form of a curtain wall, windows or a skylight with a view to the outside for an indoor pathway. Such recommendations are in line with a study on design preferences in shopping malls in Kuala Lumpur by Hami and colleagues (2018). In this study, they found that people most preferred shopping mall interiors that are wide, had a connection to the outdoors, and contained natural elements like plants and seats. Less preferred were interiors that were visually simple, or cramped (Hami et al. 2018).

For an outdoor pathway, this could be in the form of providing some open space along the pathway so that pedestrians have some buffer space, or by minimising large physical obstructions like walls or dense bushes. Where this is not possible, lining the path with small bushes that do not compromise view is recommended. This is in line with results from a study carried out by Wang and Rodiek (2019) on design preferences at urban parks in Nanjing. In this study, they found that people preferred park pathways that had a variety of plants and provided seating. However, they did not like designs that had plants blocking the view of other regions of the park, or designs with monotonous arrangements of plants (Wang and Rodiek 2019).

7. Conclusions

In line with Singapore's efforts to plan and design for more comfortable and enjoyable walking experience in high density and high intensity conditions around MRT stations, this study looked into user preferences for specific design conditions of pedestrian walkways. The results of the survey revealed that people's preference for specific design features (related to enclosure, sense of comfort, legibility, linkage and complexity) differs between crowded and non-crowded conditions and among different demographic groups.

Overall, people responded better to familiar design features (those that are typical in such environments, e.g., marble floor), rather than the more unusual ones (e.g., grass in indoor environment), possibly due to a lack of capacity to relate their sense of comfort with such atypical features. They also responded better to multi-functional features, such as prioritising seating or wayfinding aids over handrails as means of walkway division and pedestrian flow direction, or dustbins over parked bicycles, for instance.

While survey findings cannot infer any direct relationship with the sense of comfort, better understanding of people's needs and preferences can inform both retrofitting of existing and design of new walkway settings that would improve the overall experience of daily commute. They also indicate the importance of careful integration of such features into an integrated and cohesive whole, whereby functional/utilitarian and aesthetic (and restorative) aspects need to be considered simultaneously. This is challenging, due to the dynamic conditions of high pedestrian activity areas as well as the ever-changing users' needs and perceptions, which also invite the questions of flexibility, customisation and responsiveness of designs to accommodate for such changes.

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