Tactile Pavers within the Broader Universal Design Arena: What do Different Users Prefer?

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Abstract— **For a transport system to adhere to Universal Design (UD) standards, it essentially needs to be usable by all. There are currently 370 000 people with a visual/sight disability living in Cape Town [1]. Appropriate tactile paving is, therefore, required to accommodate these users. To adopt a more widely applied standard, the South African Bureau of Standards (SABS) has recently switched from 'Design for Access and Mobility, Part 4: Tactile indicators' [2] to the International Standard 'Building Construction-Accessibility and Usability of the Built Environment' [3]. The ISO 21542 offers margins regarding design requirements, therefore, allowing variation. Japan has been at the forefront of tactile paving technology. However, when reviewing the literature, very limited research was identified regarding the configuration of pavers.**

This study aims to identify the advantages and disadvantages of varying tactile paver designs for the visually impaired, as well as other user groups. A total of 57 participants took part in the study. Once the field testing was complete, tile preferences were analyzed. Across all user groups, the offset dome, warning tile, was found to be significantly preferred, due to the detectability and comfort levels offered. Regarding the two linear tiles, there was no significant preference amongst all user groups.

Keywords—universal design; tactile pavers; user comfort; South Africa

I. INTRODUCTION

Universal Design (UD) refers to creating an environment which can be understood and can accommodate all people, irrespective of ability. For a transport system to adhere to universal design standards, it essentially needs to be usable by all. According to the United Nations (www.un.org/development/desa/disabilities/resources/factsheet-on-persons-with-disabilities.html), it was estimated that there is a total of one billion disabled people globally – of which 80% are living in developing countries [4]. According to Statistics South Africa [1], there are currently 370 000 people with a visual/sight disability living in Cape Town.

For decades, tactile paving has been used in public open spaces, to accommodate the visually impaired. Tactile paving is a system of textured tiles, or blocks, that are strategically placed to assist the visually impaired on route to their respective destination [5]. There are variations of tactile paving, based on the surface profile. Surface profiles vary from country to country, but the more common ones are warning (decision point cones), linear guidance and offset warning dome profiles.

Japan has been at the forefront of tactile paving technology. In recent years it has been more common for other countries to adopt a form of tactile paving. In December 2008, the South African Bureau of Standards (SABS) adopted the '*Design for Access and Mobility, Part 4: Tactile Indicators*' [2]. These standards were based on Australian/New Zealand standards (//www.disabilityaccessconsultants.com.au/australian-standards-as1428-suite/). To adopt a more widely applied standard, SABS recently implemented the International Standard '*Building Construction-Accessibility and Usability of the Built Environment*' [3], which were published originally in 2011. Thus, the current tactile pavers, available in South Africa, are not in line with the new ISO standards. An investigation into appropriate tactile pavers that fall within ISO standard margins and suit different road users is, therefore, paramount. Internationally, materials for pavers are rubber or concrete and the ISO Standards [3] accommodates both. It is more common to see concrete pavers used in South Africa, as it is more suitable for our weather conditions. Therefore, for this investigation, only pavers with a concrete finish were used.

II. TACTILE GROUND SURFACE INDICATORS

Tactile Ground Surface Indicators (TGSIs) have the sole purpose of guiding and warning users. The difference between the warning and guiding tactile configuration is displayed in Fig. 1 and Fig. 2, respectively. The guidance tiles are placed with the long edge of the bars parallel to the direction of the path [6]. Warning tiles are placed at decision points and perpendicular to pedestrian crossings, with a 300mm buffer zone between the road edge and the pedestrian [6]. The buffer zone is placed to increase safety.

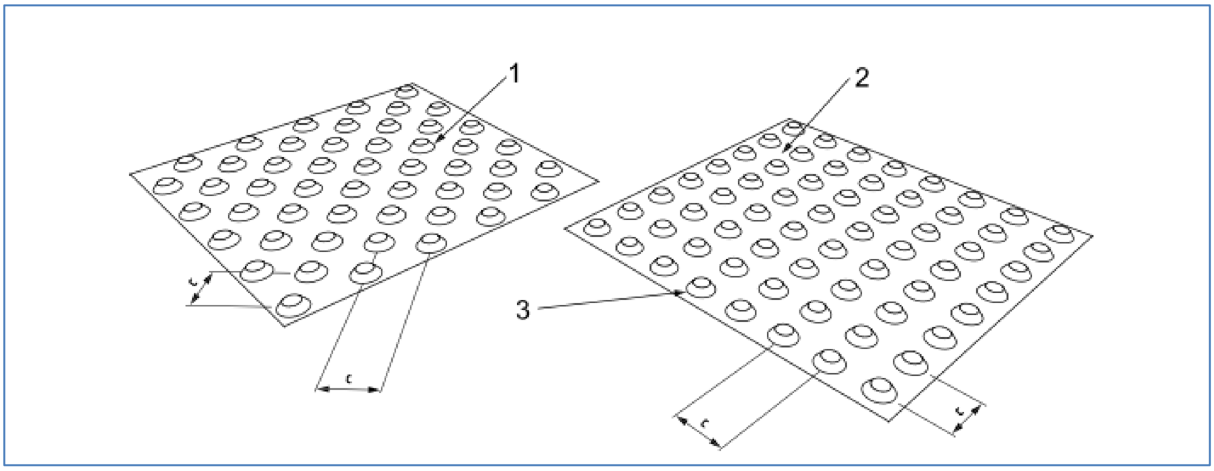

Fig. 1. Warming Tiles [3]

Within the ISO 21542 standard [3], there are margins for the design of the tactile pattern. Regarding the warning tactile (Fig. 1), domes can be arranged in diagonal rows (offset pattern) or a square grid (straight pattern). The dome height varies between 4mm to 5mm, with the base diameter having a variation of 25mm to 35mm [3]. The distances between centers of the dome are in relation to the top diameter. Table 1 shows this relation. Although the maximum spacing provides a more significant gap between the domes, resulting in improved detectability underfoot, it has an adverse effect on detectability of long cane users [3]. Therefore, a balance between the diameter and center-spacing needs to be achieved.

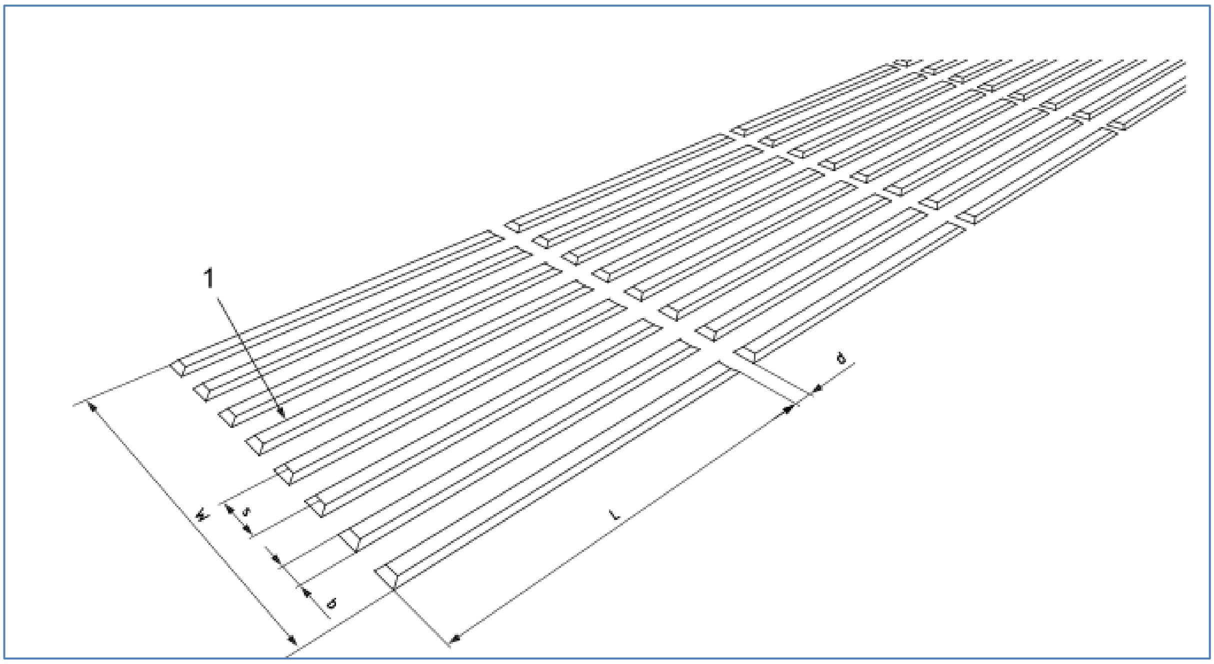

Fig. 2. Flat-Topped Linear Guidance Tactile [3]

TABLE I. SPACING IN RELATION TO DIAMETER OF WARMING TILES

Warning Tactiles		Flat-Topped Bars	
Top diameter of dome (mm)	**Centre spacing (mm)**	**Width of flat-topped guidance bar (mm)**	**Spacing (mm)**
12	42-61	17	57-78
15	45-63	20	60-80
18	48-65	25	65-83
20	50-68	30	70-85
25	55-70		

Source: ISO, 2011

Correct implementation of a TGSI will result in a more inclusive design. Inclusive design can only be achieved once it is understood how visually impaired people manoeuvre and the techniques used to gather information. Another crucial aspect is to understand the needs of other disabilities and affected user groups. The reason for this is that proposed 'solutions' to accessibility often generate problems of their own [7]. Therefore, the various affected user groups and the challenges associated with TGSIs were assessed.

III. METHODOLOGY

At the start of this study, a literature study into the background of tactile pavers and the adaptation and application in the South African context was investigated (see Fig. 3). The previous sections summarize the status-quo. An international literature regarding global practices, installation errors and shortfalls of standards was also conducted. This step has informed the study. For details on this work, the authors refer to the original thesis document [8].

Through a needs assessment of different sidewalk users, it was established that people with visual impairment, physically impairment, the elderly, distracted pedestrians, people pushing prams/trolleys and people in high heels are all, in a positive or negative manner, affected by TGSIs. Most of these groups are included in the data collection phase.

Based on a materials investigation and the newly adopted ISO 21542 standard [3], a spread of TGSIs were selected. In this study, with the limited time and budget, it appeared impossible to construct actual tactiles. It was, therefore, decided to use coated super wood as an alternative material with a concrete coating. Belting Edge Manufacturing developed the tiles. Tiger Paint Rubber Products and Mouldings assisted with the concreate coating. Two warning (one straight dome with a 50mm spacing and one offset dome with 66mm spacing) and two directional tiles (40 wide ridge with 75mm center-spacing and 27mm wide ridge with 60mm center-spacing) were manufactured. Although various designs and configurations were tested, the heights of the tile and dome/elongated bars were kept constant at 16mm and 5mm, respectively. The minimum tile dimension standard of 300x300mm was produced.

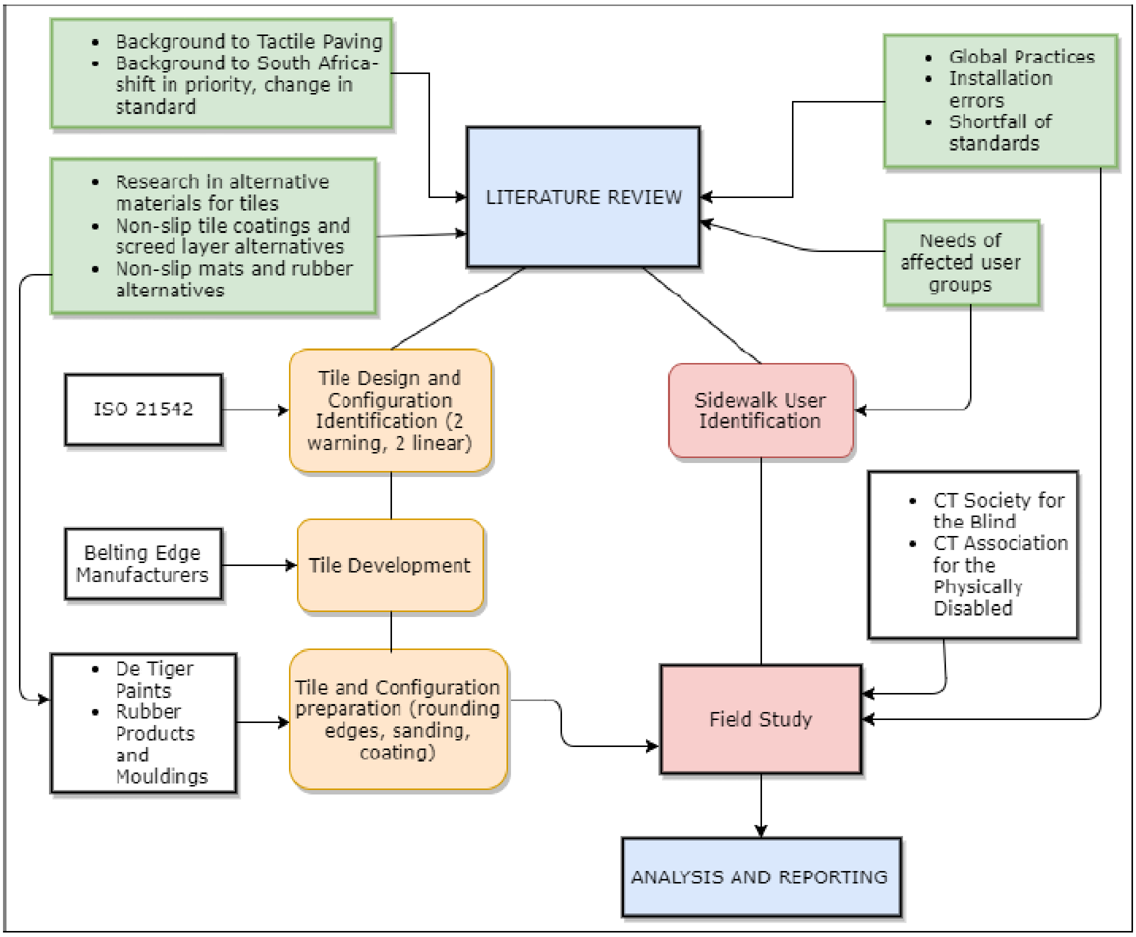

Fig. 3. Research Methodology [8]

During the field study, blank tiles were placed on either side of the linear tiles and in the buffer zone to provide a contrasting smooth surface. The width of these edge tiles was chosen to be 300mm, which resulted in an overall width of 900mm for the configuration. The increased width is to accommodate guide dog users or white cane users with a large arc radius. The blank tiles were coated with a contrasting light shade of grey to assist users who are partially sighted (Fig. 4).

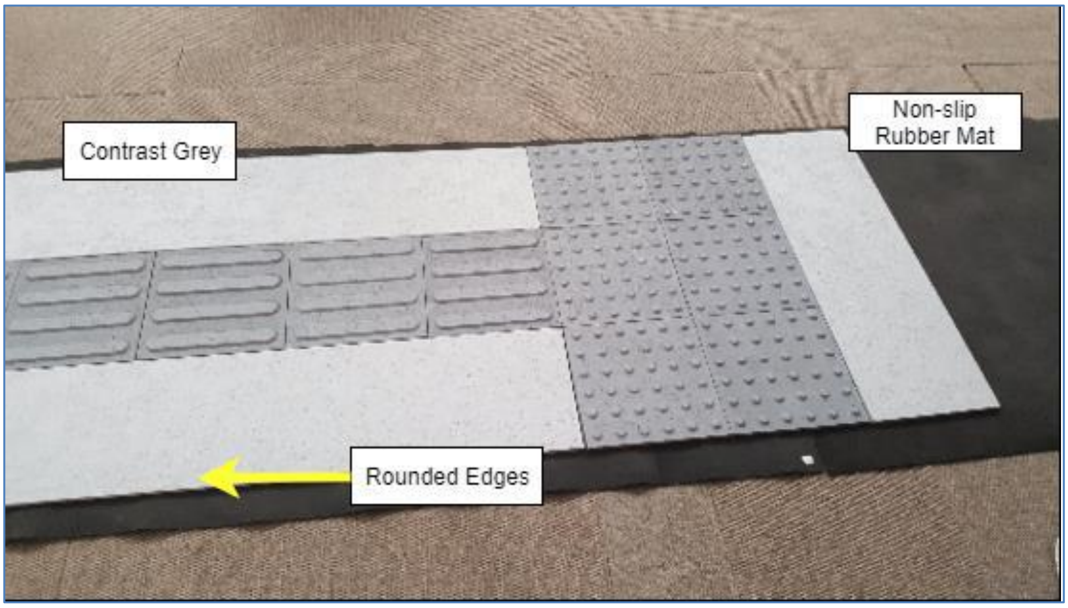

Fig. 4. Contrasting Shades used for Tiles [8]

Based on the general configuration, shown in Fig. 4, three tests were conducted, allowing each tile to be tested at least once. The tile combination of these tests were:

1. Linear Tile 1 with Warning Tile 1 (see Fig. 5),
2. Linear Tile 2 with Warning Tile 2(see Fig. 5), and
3. Linear Tile 1 with narrow ridged tile (Linear Tile 2) placed perpendicularly (see Fig. 6).

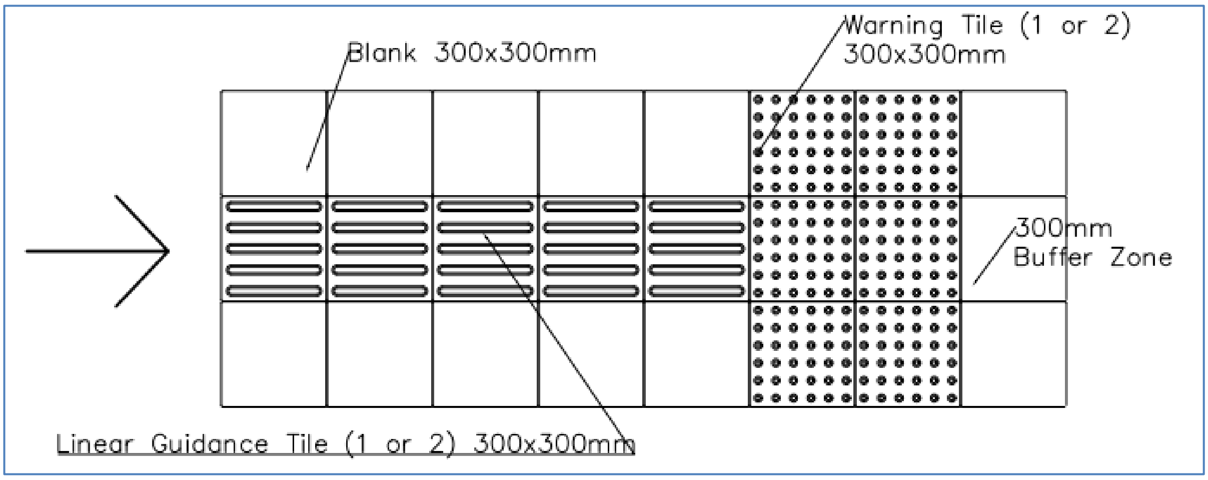

Fig. 5. General Testing Configuration [8]

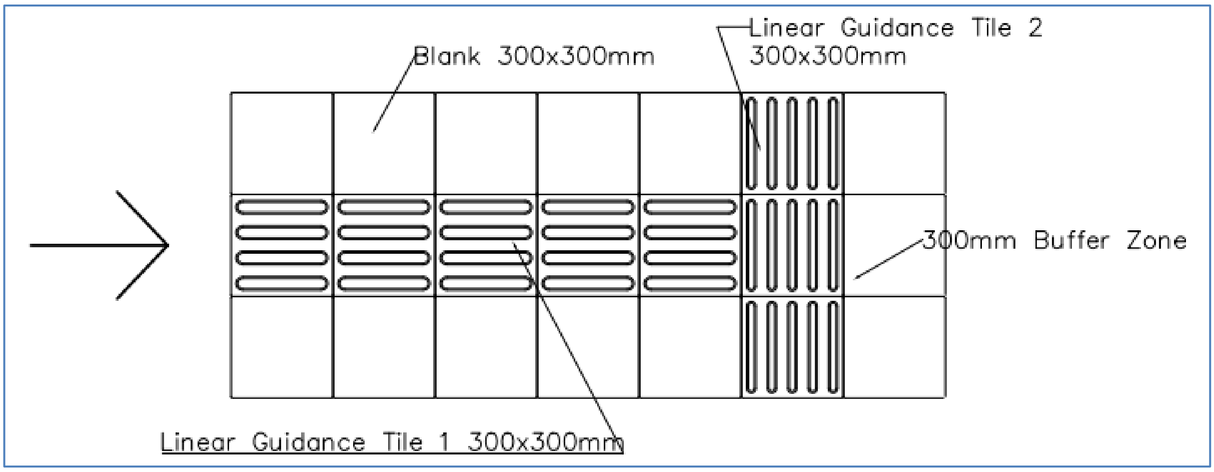

Fig. 6. Linear Only Configuration [8]

The Cape Town Society of the Blind and the Cape Town Association for the Physically Disabled assisted with the identification of users for the field study. The following users were included in the field study:

1. 26 people with vision impairment; vision impairment refers to a significant loss of vision, in both eyes, which cannot be corrected with spectacles (http://svrc.vic.edu.au/). The two main categories of vision impairment are related to the degree of loss. These categories are: partially sighted and blind,
2. 11 people with physical impairment; i.e. wheelchair users (tactile paving can cause discomfort and throw a wheelchair user off balance as the wheels travel over the nodule),
3. 10 distracted pedestrians; previous studies conducted by Hatfield and Murphy [9] found that reduced awareness, due to cell phone use, increased unsafe behavior among pedestrians when crossing a street [10]. Tactiles might warn cell phone users of danger ahead, and
4. 10 persons in high heels; although no formal literature was found, consultation with Inca Concrete Products, a TGSI manufacturer, identified that the rounded top tactile paver proved to be an immense tripping hazard for high heel users.

The data collection took place in September 2017. After the data collection, the data analysis and reporting phase began. The remainder of this paper elaborates on the data collection (including the configurations tested), data analysis and finalizes with conclusions and recommendations.

IV. Data Collection

All users were exposed to the configurations described previously. Questionnaires were applied to cover the two main aspects of this study; detectability and comfort. These questions would provide the platform to engage further into a semi-structured interview, covering aspects around the user's experience with current standard and tactile paving facilities, which they have experienced. These interviews shall be recorded and analyzed. This would provide qualitative data for this study [7]. Once users have tested the three configurations, they would be asked to provide an overall rating (1 to 5) for each tile, based on factors such as contrast (visual and textural), level of comfort and overall awareness. The rating scale is shown in Table 2.

TABLE II. RATING SCALE FOR STUDY

Scale	Description
1	Poor: No awareness, extreme discomfort etc.
2	Unsatisfactory: Minimal awareness, discomfort etc.
3	Satisfactory: Some awareness, some discomfort etc.
4	Very satisfactory: Good awareness, minimal discomfort etc.
5	Outstanding: Optimal awareness, no discomfort etc.

Once the field study was completed, various analysis and comparisons were carried out to assess if the new standard can be achieved.

V. ANALYSIS OF QUANTITATIVE DATA

A total of 57 users participated in the testing and interview. All participants completed a one-sided questionnaire consisting of questions regarding age, gender, health status and duration of impairment (if applicable). The raw data, from the field study was grouped and summarized in Table 3.

TABLE III. AGE AND GENDER PROFILE OF THE PARTICIPANTS

Age	Female	Male	TOTAL	Average age*
Visually impaired age group				
18-39 years	5	7	12	26.7±6.9
40-59 years	6	8	14	48.9±4.9
60 years and older	0	0	0	0
Total	**11**	**15**	**26**	**38.5±12.9**
Wheelchair user age group				
18-39 years	2	5	7	30.4±6.1
40-59 years	1	2	3	49.3±2.3
60 years and older	0	1	1	62
Total	**3**	**8**	**11**	**38.5±12.6**
Cell phone user age group				
18-39 years	4	6	10	21.7±2.9
40-59 years	0	0	0	0
60 years and older	0	0	0	0
Total	**4**	**6**	**10**	**21.7±2.9**
High heel user age group				
18-39 years	8	0	8	30.3±5.0
40-59 years	2	0	2	55±4.3
60 years and older	0	0	0	0
Total	**10**	**0**	**10**	**35.2±11.42**

*= Mean ± standard deviation

All participants were then requested to select a preferred linear and warning tile after testing the three configurations. The choice of the linear tile comprised of the wider ridged (Linear Tile 1) and the narrower ridged tile (Linear Tile 2). The warning tile choices comprised of the straight dome (Warning Tile 1), the offset dome (Warning Tile 2) and the narrow ridged tile placed perpendicularly (Linear 2- Warning). A tally system was then used and one point was given if the tile was preferred. If there was no preference for a tile, the point was shared. The results of the tally are shown in Table 4.

TABLE IV. TILE PREFERENCE TALLY RESULT

User Group	**Linear Preference**		**Warning Preference**		
	Wide Ridge	**Narrow Ridge**	**Straight Dome**	**Offset Dome**	**Narrow Ridge (Perpendicular)**
Visually Impaired	10.0	16.0	3.5	17.5	5.0
Wheel Chair*	4.0	7.0	1.0	10.0	N/A
Cell Phone	5.5	4.5	1.8	7.8	0.3
High Heel	6.0	4.0	0.0	8.0	2.0
TOTAL	21.5	24.5	6.3	43.3	14.3
*= Perpendicular directions, of linear tiles, were tested for the wheelchair user group					

Within the user group sections, a qualitative analysis was adopted for the major user groups i.e. visually impaired and wheelchair users. Quantitative analysis, based on the tile ratings, was used for each user group. The rating system was based on Table 2. The objective was to determine if there is a significant preference between the linear and warning tiles, respectively. This could be determined using the one-way ANOVA f-test. For these cases, H_0 (null hypothesis) was defined as "no difference in tile preference", whereas the H_1 (alternative hypothesis) was defined as "difference in tile preference". The test was carried out using the Data Analysis: One-way ANOVA Tool Pack on Microsoft Excel. A 95% confidence level ($\alpha=0.05$) was used for the analysis. The results of the analysis for the linear and warning tiles are shown in Tables 5 and 6, respectively.

Based on Tables 5 and 6 it can be concluded that there is no significant difference between the different types of linear and warning tiles.

TABLE V. ANOVA RESULTS OF LINEAR TILE TALLY FOR ALL USER GROUPS

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value*	F critical
Visually impaired user group						
Between Groups	0.29	1	0.29	0.47	0.49	4.03
Within Groups	30.95	50	0.62			
Total	**31.24**	**51**				
Wheelchair user group						
Between Groups	0.1	1	0.10	0.05	0.82	4.35
Within Groups	38.05	20	1.90			
Total	**38.15**	**21**				
Cell phone user group						
Between Groups	0.05	1	0.10	0.09	0.77	4.41
Within Groups	9.9	18	0.55			
Total	**9.95**	**19**				
High heel user group						
Between Groups	0.61	1	0.61	1.41	0.25	4.41
Within Groups	7.83	18	0.43			
Total	**8.44**	**19**				

*= p>0.05: Do not reject H_0

TABLE VI. ANOVA RESULTS OF LINEAR TILE TALLY FOR ALL USER GROUPS

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P-value*	F Critical
Visually impaired user group						
Between Groups	24.37	2.00	12.18	15.28	2.71E-06	3.12
Within Groups	59.79	75.00	0.80			
Total	**84.15**	**77.00**				
Wheelchair user group						
Between Groups	4.55	1.00	4.55	5.78	0.03	4.35
Within Groups	15.73	20.00	0.79			
Total	**20.27**	**21.00**				
Cell phone user group						
Between Groups	10.85	2.00	5.43	7.65	2.33E-03	3.35
Within Groups	19.15	27.00	0.71			
Total	**30.00**	**29.00**				
High heel user group						
Between Groups	7.55	2.00	3.78	5.52	0.01	3.35
Within Groups	18.45	27.00	0.68			
Total	**26.00**	**29.00**				

* = p<0.05: Reject H_0

VI. Analysis of Qualitative Data

The quantitative approach involved analyzing the ratings given by the visually impaired participants for each of the tiles. As there was a more significant response from visually impaired participants, a detailed analysis could be done. Therefore, the effects of the degree of visual impairment, and walking technique, on tile preference could be analyzed.

All but one of the participants could identify the four zones (linear, edge, warning and buffer) for the three configurations tested. There were no significant issues identified with recognizing the linear and warning zones. However, regarding the variable tile in the configuration, linear and warning, there was a preferred tile.

Information gathered from the semi-structured, qualitative, interviews were used to analyze quantitative data. From the semi-structured interview, partially sighted participants, who struggle with depth perception, stated that they would not, necessarily, rely upon TGSIs at an intersection approach. However, when travelling on steep topography, the visual and textural contrast, of linear tiles, is used as a guide to estimate depth. Participants further stated that they tend to be thrown off balance when travelling on an uneven surface, due to errors in depth perception. The narrow ridged tile provided less flat-topped area and, therefore, less support underfoot. As a result, participants found the narrow ridges caused them to have a temporary loss of balance. Thus, the increased flat-topped area, of the wider ridged linear tile, was preferred for these specific users. The reason for the preference was due to there being greater underfoot support, resulting in improved overall balance.

Within the most vulnerable road users, i.e. persons with vision impairment and people in a wheelchair, there is no significant difference in preference between the narrow ridge and wide ridge linear tile, as can be seen in Fig. 7. People using a long cane and people walking with an assistant have a slight preference for the narrow ridge.

The contrasting needs of those who struggle with depth perception (partially sighted) were compared with the needs of participants with little to no vision. This example is used, as it highlights the importance of comfort and awareness, and identifies the correct balance between the two. Across the partially sighted and totally blind users, the offset warning tile was significantly preferred. From Fig. 8, average tile ratings indicate that the offset tile was preferred, irrespective of the degree of visual impairment.

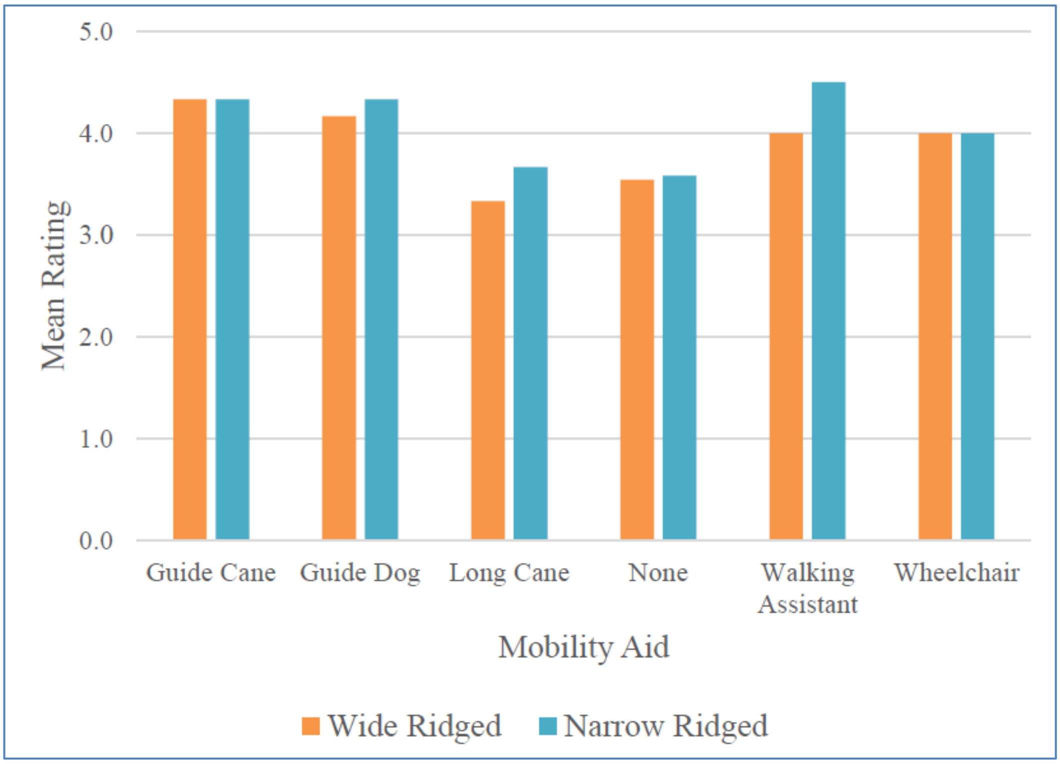

Fig. 7. Linear Tile Preference per Mobility Aid [8]

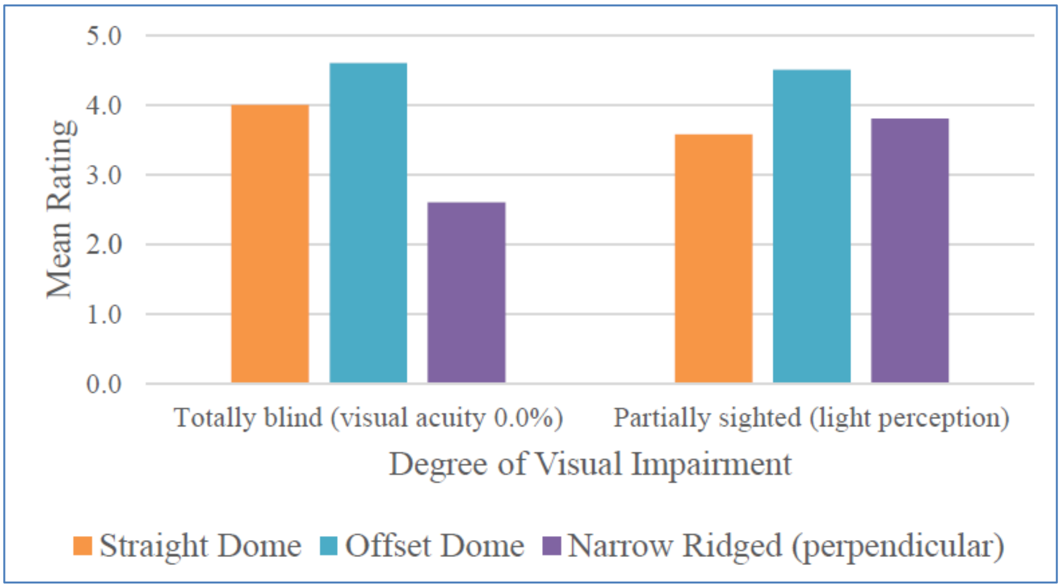

Fig. 8. Warning Tile Preference per Degree of Visual Impairment [8]

For cane users, both the straight and offset dome could be identified when transitioning from the linear zone, as the interval between ridges and domes are no longer equal. Due to the improvement in detectability, when compared to current SANS 784 [2] design, the straight and offset dome received satisfactory ratings. Overall, however, the offset dome was significantly preferred, due to the offset nature, creating a greater textural contrast (see Fig. 9).

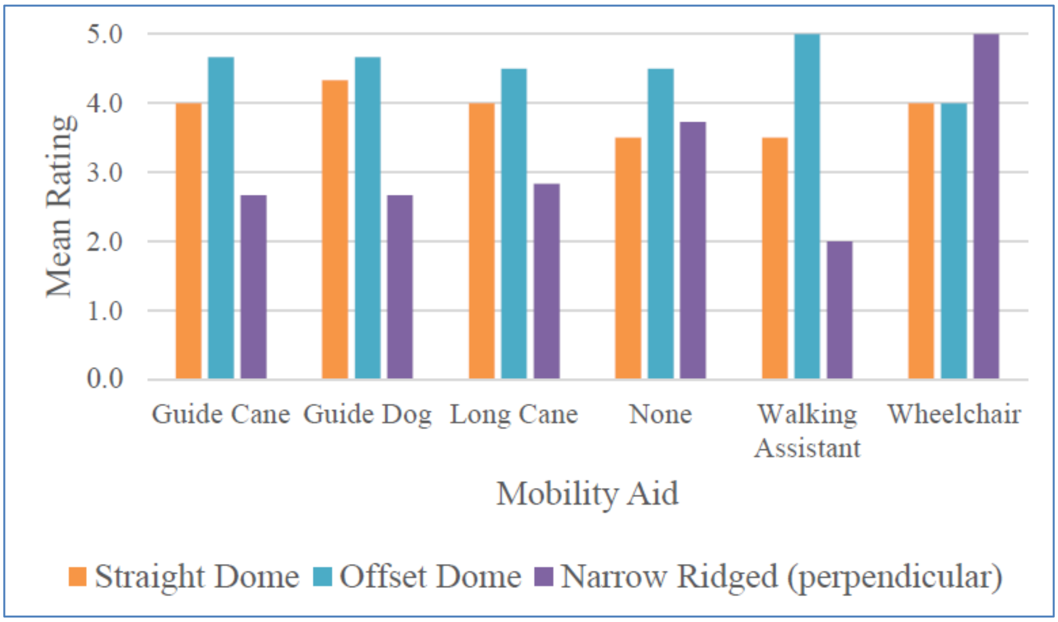

Fig. 9. Warning Tile Preference per Mobility Aid [8]

White cane users, however, struggled to identify the warning zone of the third configuration. Participants felt as if the linear tile, placed perpendicularly, could easily be confused with a change in linear direction, as opposed to a warning of an intersection approach. The one row of warning tiles was found to be an issue, as the 300mm zone offered too little tactile information, in the form of cane vibrations, from tile protrusions. Users recommended that an increased length of the warning zone could make the configuration more detectable, as there would now be a more significant number of vibrations from the increase in tile protrusions. Due to these issues, the average rating of the narrow ridged tile (perpendicular) received poor average ratings.

An interesting finding was participants making use of a combination of techniques when approaching the buffer zone. It was observed that those users making use of the touch-and-slide technique would slide the long cane between the ridges of the linear tiles, however, upon reaching the warning zone, they would adopt the constant contact, arc-like motion technique. The reason for this was that once the warning zone was detected, participants were aware that the buffer zone was approaching and, therefore, adopted the more cautious constant contact technique. In reality, this would make sense, as once the user is aware that the intersection is approaching, they would proceed with caution. For participants not making use of any mobility aid, the offset dome obtained the highest average tile rating. These participants could only rely upon tactile-foot perception and limited vision (if applicable). Therefore, due to the greater textural contrast offered by the offset warning tile, there was a higher average rating observed.

Observations were made, when participants were not able to detect the interface between the warning and buffer zone, when performing the attention-demanding task. The wide ridged tile obtained a higher average tile rating than the narrow ridged tile. However, the differences between the two ratings were found not to be significant based on the ANOVA (Table 9). The standard deviation calculated for the wide ridged tile was found to be smaller, as there was less variation in the rating. The marginally higher ratings of the wider ridged linear tile were due to participants experiencing greater support underfoot from the wider flat-topped area. Fig. 10 provides the preferences for different high heel users, while Fig. 11 illustrates the difficulties experienced by wedge users.

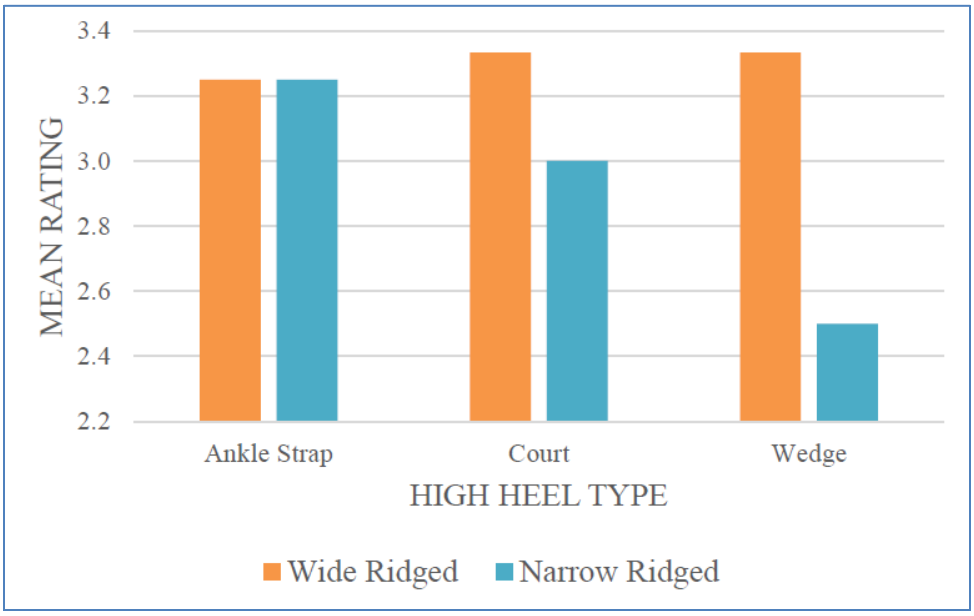

Fig. 10. Linear Tile Preference per Heel Type [8]

Fig. 11. Twist of Ankle of a Wedge User [8]

VII. Discussion

The task of identifying advantages and disadvantages of varying tactile paving designs and configurations was found by making use of a mixed method analysis. The quantitative analysis involved using the tile ratings and conducting the ANOVA test, while semi-structured, qualitative, interviews were conducted to gain users' experiences with current tactile facilities. The data, gathered from the qualitative analysis, was used to tie in with various themes from literature and test observations.

Within the visually impaired user group, the needs of the users varied. This was found to be highly dependent on factors, such as the degree of visual impairment, mobility aid, type of shoe used, personal preference etc. A significant finding, from the field study, was that participants using a white cane or guide dog, still relied heavily on tactile-foot perception as guidance. For example, those making use of the constant contact technique reported that the cane is used more as a protection measure against any obstacles in their travel path. Therefore, when comparing the tiles, it is vital that both foot and cane perception should be considered. However, participants struggled to determine the warning zone for when the narrow ridged tile was placed perpendicularly, resulting in the poor average rating ($\mu=2.85$).

For the two linear tiles, the results varied considerably. There was no significant difference ($p>0.05$), in overall preference, between the linear tiles with four wider ridges, when compared to the five narrower ridges. The reason for there not being a significant linear tile preference was due to the condition-specific attributes, of participants, in the visually impaired group. Partially sighted participants, who struggle with depth perception, preferred the wider ridges. These participants reported that the wider ridge offered greater support and balance underfoot. Fully blind, or low vision, participants' attributes were found to differ from the partially sighted, as there was a preference towards the narrow ridges. Blind participants stated that the narrow ridges had a more profound textural contrast with, not only, white cane but underfoot as well. Underfoot detection is crucial, as it was observed that tactile-foot perception is relied upon, irrespective of the presence of a mobility aid.

For the three warning tiles, however, there was a significant difference between the average rating for each tile ($p<0.05$). The offset warning dome was identified as the preferred tile amongst the entire visually impaired group ($\mu=4.56$). Participants reported that the offset domes were found to produce a more profound textural contrast, irrespective of mobility aid, and provide more significant support underfoot, therefore, providing for the needs of both partially sighted and fully blind.

The third configuration, where linear tiles were used as warning tiles, provided no significant textural contrast when transitioning from the linear to the warning zone, for blind participants, who are more reliant on awareness and detectability. Another issue was the fact that the third configuration made use of one row of warning (300mm), as opposed to the usual two rows (600mm). Participants, therefore, felt that there was not enough tactile information present before reaching the buffer zone, hence, the reason for the tile having the lowest mean rating amongst fully blind participants.

Linear tile preference, for wheelchair users, was found to be highly variable, as the wheelchair design influenced the user's experience for each configuration. Riding over the linear tiles, in the perpendicular direction, was not a major issue for users with a calf strap on their wheelchair. However, other manual wheelchair users, which did not contain the calf strap, found the movement and vibrations caused by tile protrusions to be uncomfortable, for both linear tiles. A comparison of the straight and offset warning tiles found that wheelchair users preferred the offset warning tile.

There was no significant preference between the wide and narrow ridged linear tile for distracted (cell phone) users. Some participants found the wider ridge to be more comfortable underfoot, while others preferred the narrow ridged tile, as it had a more significant contrast when transitioning between the linear and warning zone. For the warning tiles, the offset dome was found to be much more profound, in warning participants, when compared to the other two warning tiles.

The purpose of the field test, for high heel users, was to identify a tile design which offers adequate levels of comfort. All five tiles, comprising of two linear and three warnings, were designed as flat-topped. None of the participants found the maximum 5mm height, of the dome/elongated bar, to be a tripping hazard. Tile preference for the two linear tiles was found to be dependent on the walking technique of the user, as opposed to the type of heel. Within each of the high heel groups, tile preferences varied, as walking techniques varied. Participants were observed landing the heel on the flat-top, whereas other participants preferred landing the heel within the ridges of the linear tile. Slight "twists" or "rolls" of the ankle were observed for the narrow ridged tile. This resulted in some users experiencing discomfort and providing a lower tile rating, hence, this was the reason for the marginally higher average rating of the wider ridged tile. For the warning tiles, high heel users found the offset dome to provide more significant support and balance underfoot, hence, the reason for the significantly higher ($p<0.05$) average tile rating ($\mu=4.20$). However, for all three warning tiles, no ankle "twist" or "wobble" was observed.

Making use of super wood tiles allowed for ease of transportation and field testing to be convenient, particularly for vulnerable users, as the test could be set up at the premises of the respective associations. However, the test was limited to testing detectability and levels of comfort only. Mechanical properties could not be tested as the tiles, used in this study, were prototypes of concrete pavers. It is, therefore, recommended that concrete pavers be manufactured from each of the four tactile designs used in the field study. This would allow for the impact of tactile designs, on paver strength, to be determined. Strength is used in general terms and, therefore, refers to compression, flexural and shear, as well as abrasion and impact resistance.

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