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RESEARCH ARTICLE

Influence of geometry on legibility: An explanatory design study of visitors at the Kuala Lumpur City Center

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Abstract
Legibility is based on landmarks and geometry. Visitors in a space learn to "read" an area by using three- and two-dimensional cues. This research aimed to determine the responses of visitors to the influence of geometry on the legibility at Kuala Lumpur City Center (KLCC). The relationship between geometry and space legibility can affect visitors' wayfinding. In this study, visitors, including 86 respondents and 8 individuals who participated in a focus group, were surveyed through questionnaires and interviews during daytime. Results show that legibility was moderately and positively correlated with regular geometry, but legibility was negligibly affected by existing geometry. Regression analysis, *t*-test, ANOVA, and scheme coding of qualitative data suggested that regular geometry used in urban spaces might strongly improve legibility. For urban designers, regular geometry associated with landmarks enhances legibility.

1. Introduction

Geometry is associated with legibility (Critchlow, 1987, 1976; Hecht, 1988). Regular geometry applied to new tangible products has been widely explored, but the intricacies of the perception on legibility relative to space have yet to be described (Stanford, 2007; Walsh and Cummins, 1976). In most cases, visitors are exposed to irregular geometries utilized for

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urban spaces, where an increasing number of skyscrapers destroy landmarks (Etienne, 2003; Etienne et al., 1998). Geometric designs may also differ from urban designs used for city development (Lee et al., 2012).

Landmarks or geometry is used as a basis for legibility. For example, visitors in a space learn to “read” an area by using two- and three-dimensional cues (Fig. 1) (Sheynikhovich and Arleo, 2010). When finding their way, visitors likely apply landmarks as visual cues in a three-dimensional spatial configuration (Raubal and Winter, 2002). In geometry, human spatial navigation is incorporated in the second dimension (Kelly and Bischof, 2008). Thus, landmarks and geometry can affect a visitor's orientation and navigation (Sovrano et al., 2005). With the development of skyscrapers, regular geometric design may be more reliable than landmarks alone during landscape reading and wayfinding (Sheynikhovich and Arleo, 2010).

Animals and young children, their perception on legibility based on geometry, and the association of legibility with landmarks have been widely considered in legibility-related studies. However, spaces and their relationship with visitors have yet to be fully explored. As such, legibility in spaces should be further investigated to describe their relationship comprehensively. Although legibility in general has been extensively investigated, the legibility of spaces from a visitor's viewpoint has been rarely determined (Dalton and Bafna, 2003; Golledge, 1999; Lynch, 1960). Information on the effects of landmarks on legibility is also limited (Darken and Sibert, 1996; Hartley et al., 2004; Lynch, 1960; Magliano et al., 1995; Ruddle et al., 1999).

This study generally aimed to investigate the visitors' attitudes toward Kuala Lumpur City Center (KLCC) by using an explanatory design method and to determine the visitors' views on the geometry and legibility of KLCC.

This study specifically aimed to achieve the following objectives:

- To describe the explanatory design method for the validation of the process used in our study;
- To investigate the visitors' views on the relationship between legibility and geometry in urban spaces.

KLCC was selected as the study area because it boasts of historical buildings and Malaysian heritage. For instance, Jalan Ampang Street passes through this area. To determine the visitors' perceptions and space-related problems in this area, we conducted a literature review and distributed a questionnaire. We then considered the obtained data to provide recommendations for the improvement of KLCC.

In previous studies, geometry is applied to experiments involving rats to determine the effect of geometry on wayfinding (Yaski and Eilam, 2007; Yaski et al., 2011a, 2012). In our study, geometry was defined in terms of its effect on legibility and visitors' wayfinding in urban spaces. Difficulties in pedestrian's wayfinding through KLCC were also determined by performing observations during daytime. Significant differences in the perception between genders were not evaluated. Visitors who traveled by car or public vehicles and navigation via computer, robot, or other independent or mechanical tools were also excluded.

The remaining parts of this paper are structured as follows: Studies on legibility, landmarks, and geometry are reviewed. The research methods and procedures used in our study are then described. Our results are subsequently discussed. Implications, limitations, and directions for future research are presented in the last section.

2. Legibility perception of urban space

People understand and recognize urban spaces. Individual features are affected by the cognitive processes of recognition (Koseoglu and Onder, 2011). A cognitive map can be described as the image of spaces recognized by the human mind (MacInnis and Price, 1987). The ability to recognize urban spaces is reduced by vague and complex data (Fig. 1) (Cangoz, 2005).

The mechanism used by humans is similar to that used by computers (Cangoz, 2005). However, the treatment of keywords and the diagram of the human mind is composed of an emotional element (Sacks, 2007). Emotions run deeper than recognition (Cangoz, 2005) and attitudes (Sacks, 2007). The human mind is also adaptive to the level of accessible perceptual data (Hölscher et al., 2011).

The shortest path is not always chosen when people travel. Instead, visitors may refer to landmarks (Graham et al., 2003), follow the geometry of a space (Avni and Eilam, 2008; Dussutour et al., 2005; Hoffmann, 1983; Jeanson et al., 2003; Pratt et al., 2001; Vasquez et al., 2002), focus on gathering data, or visit familiar places (Alstott, 2007). For these purposes, visitors rely on exterior and interior cues incorporated in their representation of an urban space (Etienne, 2003; Etienne et al., 1998; Shettleworth and Sutton, 2005; Sovrano et al., 2005). This spatial image enables route configuration between an origin and destination and between distance and direction determination (Golledge, 1999). These processes have been shown in various investigational environments, such as urban space (Gould et al., 2009; Walsh and Cummins, 1976).

Different types of urban spaces, including squares and streets, have been established. Our study aimed to determine urban space geometry and its effects on legibility.

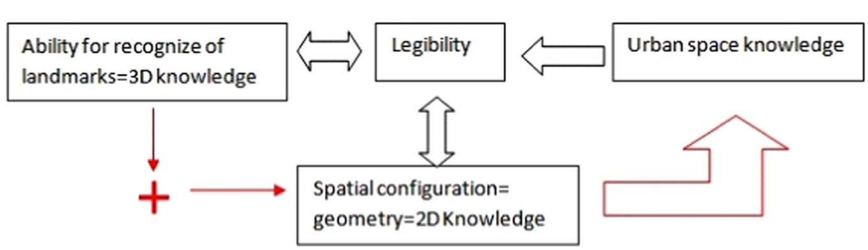

Fig. 1 Mechanism of legibility.

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Lynch (1960) believed that coherence, unity, and clarity are essential for legibility (Dalton and Bafna, 2003). Behavioral studies have shown that the environment is the basis of neurobiological information and thus explains the lack of competition between geometry and landmarks on legibility (Sheynikhovich and Arleo, 2010).

2.1. Landmarks as three-dimensional cues for urban space knowledge

Some psychological experiments have demonstrated that visitors use landmarks (Darken and Sibert, 1996; Magliano et al., 1995; Ruddle et al., 1999) in the manner described by Lynch. The uniqueness of a landmark is an important physical aspect. Landmarks, together with paths, districts, edges, and nodes, are also typically found in an urban space. Furthermore, landmarks are identified by their context and location (Lynch, 1960) and used to determine direction when this parameter is combined with a neural representation stored in the hippocampus (Hartley, 2004).

Landmarks are categorized into two groups: global and local (Steck and Mallot, 2000). Global landmarks are observable from great distances, whereas local landmarks are smaller than global landmarks in scale and can only be perceived when observers approach such landmarks. Raubal and Winter (2002) stated that three factors affect a landmark's prominence. These factors are visual salience (form, color, and facade), semantic salience (cultural and historical value), and structural salience (location). Although visual salience (Lee et al., 2006) or shape (Nardini et al., 2009) have been extensively investigated, semantic salience and location have yet to be examined. The effect of non-observable landmarks is frequently detected in reorientation tests on young children and animals (Cheng, 1986; Hermer and Spelke, 1994; Wang et al., 1999). Disorientation may also be attributed to the absence of landmarks (Lee et al., 2012). Adult visitors in urban space should be further explored to clarify this phenomenon.

2.2. Geometry as a two-dimensional cue for urban space knowledge

According to Plato, geometry is defined as “the measurable earth”, “earthly measurements”, or “spatial measurements” (Critchlow, 1976). Geometry is the language of shapes or the logic of relationships between shapes.

Euclidean and non-Euclidean geometries may be familiar ideas, but fractal geometry has yet to be fully understood. Fractal geometry was introduced by Benoit Mandelbrot in 1982 and has been used in architecture (Joye, 2011). Geometry has been applied to buildings and urban design since the earliest of times. This field of study was pioneered by ancient Greeks. Geometry was also used by other ancient civilizations in their architecture (Critchlow, 1976, 1987; Hecht, 1988).

Geometry is one of the highest achievements by humans, but the foundations of this field are obscure. Geometry is also applicable to human navigation (Lee et al., 2012). Geometric knowledge is also deeply rooted in navigational processes; for instance, children navigate by using properties from Euclidean geometry (Lee et al., 2012). The reorientation behavior of young children depends on geometry (Hupbach and Nadel, 2005). In other studies, rats check the geometric characteristics of a particular approach close to their destination. Rats mainly use geometric orientation methods, such as landmark use (Cheng, 1986). Although geometric features are relevant, a primary knowledge regarding the environment influences the significance of geometric and feature cues. In other words, adult visitors use a flexible plan to program spatial data (Kelly and Bischof, 2008).

Animals and young children use different types of cues when they recall the location of a destination (Kelly and Bischof, 2008). Our study investigated how adult visitors used geometric and feature cues when they approach a destination in the KLCC.

Geometric is related to feature data. Although feature data are more biased than geometric data, feature data play a significant role. The acceptance of similar fine-grained analyses in studies on spatial cues is a significant component to understand complex relationships regarding spatial navigation (Kelly and Bischof, 2008).

Numerous cues are used by individuals to remain oriented or to reorient themselves as they move through an environment. The geometry of a built environment is also used to remain oriented in an urban space (Cheng, 1986). Extended built environments create geometric cues, such as intersecting streets or walls in a room. Built environmental geometry can provide clear cues for self-location (Hermer and Spelke, 1994; Kelly et al., 2008), and two cues are essential for urban-space orientation: feature cues and geometry (Cheng and Gallistel, 2005).

The hippocampus of animals plays a significant role in learning the geometric characteristics of a space. However, navigation based on geometric data is supported by “proximal cues for the target location”. Animals navigate by using geometric environmental cues and masking properties associated with the use of feature data (Vargas et al., 2011).

3. Methodology

3.1. Explanatory design

An explanatory design consists of two separate phases, namely, quantitative and qualitative stages (Creswell et al., 2003). In this method, quantitative and qualitative data were collected and analyzed. Qualitative data help explain the quantitative results. Quantitative and subsequent analyses aim to provide a general understanding of the research problem. In this study, qualitative analysis more thoroughly explains statistical results by surveying the views of research participants (Creswell et al., 2003; Tashakkori and Teddlie, 1998). Qualitative analysis is a common method used for multidisciplinary studies, such as social and behavioral research and urban design (Creswell et al., 2003).

Quantitative data were validated on the basis of the survey results. First, significant quantitative survey results were determined. Next, the underlying causes for these results were discussed. The collection of qualitative data was completed by interviewing participants who could efficiently explain the results.

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3.2. Participants

The following methods were proposed in accordance with the general guidelines for sampling designs in social sciences research (Collins et al., 2006) and a minimum sample size recommendation for quantitative and qualitative research.

(1) For the correlation design, 64 participants were selected for the one-tailed hypotheses and 82 participants were examined for the two-tailed hypotheses (Collins et al., 2006).
(2) The qualitative focus group comprised 6–12 participants (Brown, 1996; Sekaran, 2003).

The target population for this study consisted of visitors who visited Kuala Lumpur in 2013. The unit of analysis was an individual visitor in KLCC. Visitors were randomly selected from a group of local and foreign visitors, who visited KLCC and Ampang Street from May 1, 2013 to August 1, 2013 and who provided their addresses for research purposes. This group of participants served as a sample. A mail-survey questionnaire was sent to all 300 respondents of the sample to ensure that the sample size would be large enough for the structural equation model based on the recommendations made by Creswell et al. (2003) and to account for the effect of the low response rate normally associated with mail-in surveys. The final sample included a total of 86 usable questionnaires, which were then analyzed.

3.3. Procedures

3.3.1. Quantitative data

3.3.1.1. Data collection. The first questionnaire was pre-tested on a sample of 25 visitors by using a collaborative participant pre-testing method. Data were collected from May 2013 to August 2013 via mail and social network surveys. Follow-up surveys were sent to respondents who have not returned their surveys within a one-month period. No incentives were provided to respondents who completed the questionnaires.

3.3.1.2. Measures. Previously described procedures were applied to assess the respondents' views on the legibility of spatial configurations and the effect of geometry on legibility (Sekaran, 2003). This measure included 14 Likert scale statements with the following scale points: 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, and 5=strongly agree. The items were randomized in the questionnaire to minimize the effect of order bias.

The items were used to evaluate the effect of each particular element on legibility. It also indicates Cronbach's alpha reliability coefficient of each of the three sub-dimensions in the scale. The geometry subscale consisted of 8 items (a=0.781), the legibility subscale included 4 items (a=0.93), and the landmark subscale contained 2 items (a=0.797).

3.3.2. Qualitative data

A qualitative study was performed to examine the geometrical knowledge and understanding required by visitors to read an urban space in KLCC and Ampang Street and to determine the effects of the landmarks and geometry of a space on the legibility of the space. Wayfinding behaviors were also investigated. This study also aimed to understand the gaps between the effect of geometry on legibility and wayfinding experienced by visitors as they approached KLCC and Ampang Street.

Five interview questions were designed to understand the effects of geometry and landmarks on the legibility of KLCC and the wayfinding behavior of visitors. A follow-up interview was conducted to determine the visitors' opinions and collect their suggestions on how the geometry of the space could be used to improve the legibility of urban space.

The survey designed for the visitors comprised multiple-choice questions to identify the geometry used for visitor wayfinding, understand the effect of landmarks on visitor wayfinding behavior, determine the geometry used to navigate spatial configurations, and discover the geometry that positively affected legibility. The presence of any gap between geometric and non-geometric space was solicited from visitors by using the questionnaire Their behavior to reduce these gaps and develop wayfinding methods was also determined.

Content validity was performed to demonstrate the accuracy of the measurements. Validity was defined as "the degree to which a test measures what it claims, or purports, to be measuring" (Brown, 1996). The types of evidence in support of content validity include the judgments of field experts, theories on relevant behaviors from all fields, and high internal consistency or reliability (Sekaran, 2003). To ensure content validity, we obtained expert views. For this purpose, a set of questionnaires was distributed to academicians to determine how each item satisfied the study objectives. Specialists in the fields of architecture, urban design, and statistics helped improve the questions to validate the content of the research instrument. Geometry and legibility definitions should be clearly explained and conceptualized in the survey.

3.4. Data analysis

Data were analyzed quantitatively and qualitatively. Quantitative analysis was conducted using descriptive regression, t-test, and ANOVA. Qualitative data were examined through scheme coding.

Payne (1995) indicated that qualitative data analysis is optimally performed by dividing the responses into short phrases. This method is an important approach to code the data gathered through interviews or open-ended questionnaires. In this method, each phrase should refer to a single-task statement or reference to the subject. These segments can then be coded and analyzed. Similarly, Keys (2000) suggested that data should be transcribed in full and then broken up into clause-length segments. Using this method for coding and categorization, we could identify the perceptions of foreign and local visitors regarding the landmarks, geometry, and legibility of KLCC.

4. Results

4.1. Quantitative data

Table 1 provides a socio-demographic profile of the respondents of this study. The sample was slightly dominated by

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Table 1 Socio-demographic profile of respondents.

	Visitors $n=86$	Percentage %		Visitors $n=86$	Percentage %
Gender			**Race**		
Male	48	56	Local (Malay, Chinese, and Indian)	18	20.9
Female	38		Foreign visitors	68	79.1
Age			**Length of stay in KL**		
Year < 20	3	3.5	1 week	45	52.3
21-30	20	23.3	2 weeks	16	18.6
31-40	40	46.5	3 weeks	11	12.8
41-50	14	16.3	More than 3 weeks	14	16.3
51-60	8	9.3			
Year > 60	1	1.2			

male respondents (56%), and the majority of the respondents belonged to the 31–40 age group. Approximately 79.1% of the respondents were foreign visitors and 52% of the respondents stayed in Kuala Lumpur for one week.

Descriptive statistics suggested that the effects of the existing geometry on the legibility of Ampang Street and KLCC yielded the following data: $M=3.38$, SD=1.190 and $M=3.34$, SD=1.289, respectively. These values indicated that existing geometry influenced the legibility of these spaces.

The legibility of KLCC ($M=3.00$, SD=1.58) was higher than that of Ampang Street ($M=2.55$, SD=1.165). Thus, the factors that affected the legibility of KLCC included landmarks and planned configurations. These factors were more effective in KLCC than in Ampang Street.

Landmarks, specifically the Petronas Twin Towers, exhibited a greater effect on the legibility of KLCC ($M=3.86$, SD=1.118) than on the legibility of Ampang Street ($M=3.56$, SD=1.154). Therefore, the Petronas Twin Towers provide a stronger visual presence than Ampang Street does.

The mean (M) visitor's perception of the legibility of KLCC is presented in Table 2. The highest legibility level was associated with the “effect of the landmarks in KLCC” ($M=3.86$, SD=1.118) and the lowest legibility level was associated with the “legibility of Ampang Street” ($M=2.55$, SD=1.165). On average, landmarks elicited the greatest effect on legibility.

A total of 48 males and 38 females participated in this study. Table 3 presents the descriptive statistics for the participants on the basis of their gender. The means and standard deviations of male and female perceptions regarding legibility and effective elements are different. On average, males exhibit higher legibility and effective elements than females do. However, significant differences between the genders were not considered in this study and thus should be further investigated.

Table 4 shows the means and standard deviations obtained from visitors who stayed in Kuala Lumpur for one week or even longer. The mean score of stays for more than three weeks is higher than any other score. The mean perception of legibility between the groups that stayed for more than three weeks in Kuala Lumpur and one week or three weeks significantly differed ($p=0.007<0.05$). Likewise, the mean perception of legibility between the groups that stayed for more than three weeks and two weeks significantly differed ($p=0.00<0.05$). However, the mean perception of legibility among the groups who stayed in Kuala Lumpur for one, two, and three weeks did not significantly differ ($p=0.367$, 0.997, $0.591>0.05$).

Table 2 Visitors' perception of the legibility of KLCC ($n=86$).

Perceived legibility	M	SD
Vicinity of KLCC has legibility	2.7733	1.04785
Ampang Street	2.55	1.165
KLCC	3.00	1.158
Effect of geometry	3.3605	1.14699
Ampang Street	3.38	1.190
KLCC	3.34	1.289
Effect of landmark	3.7093	1.03601
Ampang Street	3.56	1.154
KLCC	3.86	1.118

Note: Scale values ranged from 1 (strongly disagree) to 5 (strongly agree); a low mean score corresponds to a high legibility level associated with that particular aspect. M=mean, SD standard deviation.

Significant differences between groups were determined through one-way ANOVA (F (3,162)=8.626, $p=0.00$). Tukey's post-hoc test revealed that the length of stay in Kuala Lumpur was significantly shorter after staying for one week (2.74±1.05 min, $p=0.367$), two weeks (2.37±0.99 min, $p=0.591$), and three weeks (2.68±0.75 min, $p=0.992$) than that for more than three weeks (3.39±1.03 min, $p=0.007$).

One-way ANOVA between subjects was conducted to compare the effect of the length of stay on a visitor's ability to perceive legibility. The length of stay significantly affected the visitors' perception on legibility [$p<0.05$, F (3, 162)=8.626, $p=0.000$]. Post-hoc comparisons with Tukey's HSD test indicated that the mean score of the visitors who stayed longer than three weeks ($M=3.39$, SD=1.03) is significantly different than that of the visitors who stayed for one week ($M=2.74$, SD=1.05). However, two- or three-week visits ($M=2.37$, SD=0.99, and $M=2.68$, SD=0.75, respectively) did not significantly differ from one-

Table 3 Visitors' opinions regarding the legibility and effective categories in terms of male and female participants.

	Male (n=48)		Female (n=38)		Total (n=86)	
	M	SD	M	SD	M	SD
Vicinity of KLCC with legibility	3.1875	0.98188	2.2500	0.89102	2.7733	1.04785
Effect of existing geometry	3.5312	0.96429	3.1447	1.32496	3.3605	1.14699
Effect of landmark	4.0521	0.89466	3.2763	1.05072	3.7093	1.03601

Table 4 Means and standard deviations for responses on the legibility of KLCC with various lengths of visits.

	1 week (n=45)		2 weeks (n=16)		3 weeks (n=11)		More than 3 weeks (n=14)	
	M	SD	*M*	SD	*M*	SD	*M*	SD
Vicinity of KLCC has legibility	2.7444	1.05863	2.3750	1.00830	2.6818	0.78335	3.3929	1.05936
Existing geometry's effect	3.1778	1.20678	3.2188	1.32877	3.7727	0.81742	3.7857	0.80178
Landmark's effect	3.8333	0.98857	3.1875	1.01448	3.182	1.25045	4.2143	0.72627

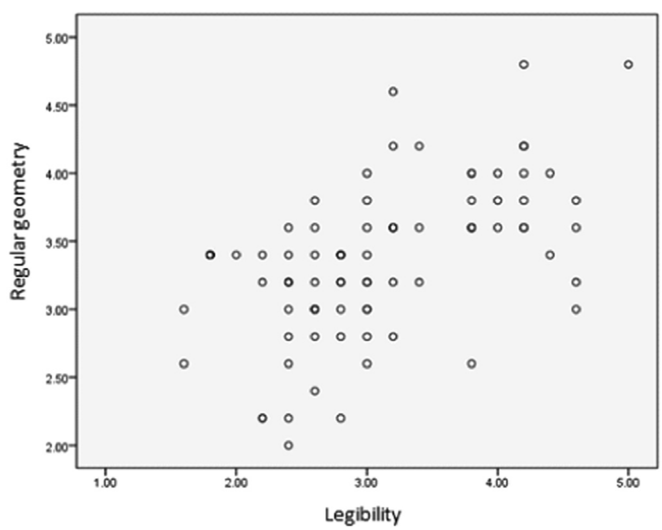

Fig. 2 General relationship between legibility and regular geometry.

week stays. These results suggest that staying for more than three weeks affected legibility. Visitors can easily read the landscape when they stayed for more than three weeks in a city. However, the length of stay must be longer than three weeks to observe an effect.

Pearson's product-moment correlation coefficient was calculated to assess the relationship between legibility and regular geometry. The two variables were moderately and positively correlated (r=0.531, n=86, p=0.000). A scatter plot summarizing the results is shown in Fig. 2. The increase in the quality of regular geometry is correlated with the increase in legibility.

Pearson's product-moment correlation coefficient was computed to assess the relationship between the legibility and existing geometry of KLCC. The correlation between the variables was negligible (r=0.150, n=86, p=0.169). A scatter plot summarizing the results is shown in Fig. 3. Overall, the legibility of KLCC was slightly correlated with its existing geometry.

4.2. Qualitative phase

Each interview was recorded and transcribed. The interview data were presented in a data analysis matrix. Our literature review was presented in our study. After re-confirming the data numerous times, we established a general coding framework.

Analysis was completed within three months. All transcribed extracts were coded by two researchers. Each word, sentence, and paragraph was coded according to the coding scheme. The eleven discovered themes were the same as those presented in the literature review. These themes include ease of understanding, unity and clarity, difficulties caused by vagueness and complexity, importance of location, helpfulness for distinguishing a destination, clarity of forms and contrasts from the context, crucial location, being observable from a distance, logical relationship between shapes, incorporation with the landmark, and procedure for improving legibility. The data were further

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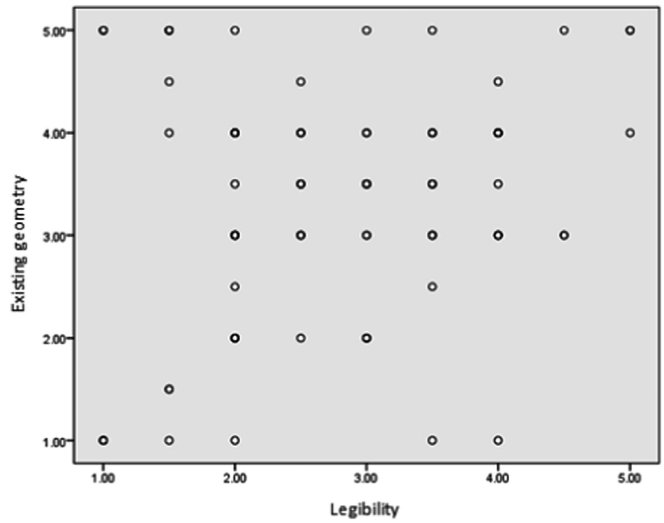

Fig. 3 Relationship between legibility and existing geometry of KLCC.

Table 5 Frequencies and percentages of the coding of themes and sub-themes.

No	Theme	Sub-theme	Fr (M)	Fr (F)	Fr (T)	% (T)
1	Perception of legibility in the vicinity of KLCC	Perception attitude (positive)	1	2	3	33
2		Perception attitude (negative)	3	3	6	66
3		Ease of understanding, unity and clarity	1	1	2	22
4		Difficulty in perception resulting from vagueness and complexity	3	3	6	66
5	Landmark (Petronas Twin Tower) as three-dimensional urban-space knowledge	Importance of the location	3	5	8	88
6		Helpfulness for distinguishing the destination	3	3	6	66
7		Clarity of forms and contrasts with context	4	3	7	77
8		Crucial location	1	1	2	22
9		Observable from a distance	2	1	3	33
10	Geometry as two-dimensional urban-space knowledge	Logic of relationship between shapes	1	1	2	22
11		Incorporation to landmark	1	3	4	44
12		Procedure of improving legibility	2	3	5	55
13		Application	3	3	6	66

Fr: Frequency, %: Percentages (=Fr (T)/9), M: More than three weeks, F: Fewer than three weeks, T: Total.

divided into the sub-themes of positive and negative attitudes.

The themes and sub-themes were determined by using the coding scheme (Table 5). After coding, we found that the most common themes included legibility, landmarks, and geometry. The themes and sub-themes presented in Table 5 are based on Fig. 1.

5. Discussion and conclusions

This study investigated the effects of geometry and landmarks on the legibility of a landscape. This research contributes to architecture and urban design by demonstrating the importance of geometry as an influencing factor in legibility. Tangible goods or functional performances have been considered to develop and evaluate related studies except those of Yaski et al. (2011a), who investigated geometry and path shapes. Yaski et al. (2011b) also examined the spatial behavior of rats traveling in straight or circuitous paths. Lee et al. (2012) analyzed navigation in terms of geometric knowledge. Lee et al. (2012) further explored the spatial navigation of young children during the completion of a reorientation task. In our study, a more varied spectrum of visitor behavior in an unfamiliar space was investigated.

This inconsistency may be attributed to the differential nature of the two constructs. Regular geometry likely promotes a positive relationship and thus enhances legibility. The effects of landmarks may become positive as legibility increases. In space geometry, regular geometry positively affects legibility (Yaski et al., 2011a, 2012). However, the relationship between regular geometry and legibility in unfamiliar spaces remains untested. Relevant conditions should be examined to provide insights into the negative relationship between the existing geometry and

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the legibility of KLCC. Approximately 80% of the respondents in our study agreed that regular geometry affected legibility. A regular geometric space may positively affect the legibility of KLCC.

In a separate analysis, visitors' perceptions regarding the physical and psychological characteristics, including landmark, geometry, and legibility, of KLCC were compared. Our results revealed that the current geometry of the space exhibits a negligible effect on legibility, and landmarks provide greater influences on legibility. These results are consistent with those of Hartley et al. (2004). Assuming that legibility represents the aspects of an established environment, we observed that a visitor's wayfinding is hindered by irregular geometry and insufficient landmarks. However, these conclusions should be verified across different urban spaces.

Our results also indicated that the visitors' gender is another significant factor that affects the ability to perceive the legibility of a space. However, the role of gender in understanding legibility should be further investigated.

Legibility is highly significant for visitors who stayed in Kuala Lumpur for more than three weeks. Our results supported those of earlier urban spaces studies (Koseoglu and Onder, 2011). The length of a visitor's stay significantly affects their ability to read the landscape of KLCC [$p<0.05$ level, $F(3, 162)=8.626$, $p=0.000$]. However, the length of stay must be more than three weeks to observe the corresponding effects.

Pearson's product-moment correlation coefficient showed that legibility is moderately positively correlated with regular geometry ($r=0.531$, $p=0.000$). Our results are consistent with those of Lee et al. (2012). However, the two variables exhibit an unexpected negligible correlation ($r=0.150$, $p=0.169$). These findings suggest that regular geometry may improve legibility.

Our qualitative findings showed that most visitors (66%) staying for less than three weeks in Kuala Lumpur exhibited negative attitudes toward the legibility of the KLCC because of the vagueness and complexity of space. Most of the visitors stated that landmarks are necessary to recognize a location (88%) and to determine a destination (66%). Fewer visitors believed that the crucial location of a landmark is correct (22%) and landmarks are observable from a distance (33%).

In contrast to their satisfaction with current geometry (22%) and combination of current geometry and landmarks, a weak legibility was observed by 44% of the visitors. Our study recommends the use of regular geometry to improve the legibility of KLCC (55%). Our study also suggests the actual use of regular geometry (66%).

References

Alstott, J., 2007. Security, Information, and Memory Determine Locomotor Exploration in Rattus Norvegicus. Bloomington, Indiana.

Avni, R., Eilam, D., 2008. On the border: perimeter patrolling as a proposed transitional exploration phase from piloting to orienting in a diurnal rodent, the fat sand rat (Psammomy obesus). Anim. Cogn. 11, 311–318.

Brown, J.D., 1996. Testing in language programs. Modern and Interactive Approach to Learning Engineering Mathematics, British Journal of Educational Technology. Prentice Hall Regents, Upper Saddle River, NJ 32(2), pp. 195–207.

Cangoz, B., 2005. Gecmisten gunumuze bellegi aciklamaya yonelik yaklasimlara kisa bir bakis. Hacettepe Universitesi Edebiyat Fakultesi Dergisi 22(1), pp. 51-62.

Cheng, K., 1986. A purely geometric module in the rat's spatial representation. Cognition 23, 149–178.

Cheng, K., Gallistel, C.R., 2005. Shape parameters explain data from spatial transformations: Comment on Pearce et al. (2004) and Tommasi and Polli (2004). J. Exp. Psychol.: Anim. Behav. Process. 31 (2), 254–259.

Collins, K.M.T., Onwuegbuzie, A.J., Jiao, Q.J., 2006. Prevalence of mixed-methods sampling designs in social science research. Eval. Res. Educ. 19 (2), 83–101.

Creswell, J.W., Plano Clark, V.L., Gutmann, M., Hanson, W., 2003. Advanced mixed methods research designs. In: Tashakkori, A., Teddlie, C. (Eds.), Handbook of Mixed Methods in Social and Behavioral Research. Sage, Thousand Oaks, CA, pp. 209–240.

Critchlow, K., 1976. Islamic Patterns: An Analytical and Cosmological Approach. Schocken Books, Thames and Hudson, London, UK.

Critchlow, K., 1987. Order in Space: A Design Source Book. Thames and Hudson, USA.

Dalton, R.C., Bafna, S., 2003. The syntactical image of the city: A reciprocal definition of spatial elements and spatial syntaxes. Paper Presented at the 4th International Space Syntax Symposium London.

Darken R.P., Sibert, J.L., 1996. Wayfinding strategies and behaviors in large virtual worlds. In: Proceedings of the Paper presented at the CHI '96 SIGCHI Conference on Human Factors in Computing Syste. New York, NY, USA.

Dussutour, A., Deneubourg, J., Fourcassié, V., 2005. Amplification of individual preferences in a social context: the case of wall-following in ants. Proc. R. Soc. B Biol. 272, 705–714.

Etienne, A., 2003. How Does Path Integration Interact with Olfaction, vision, and the Representation of Space?. In: Jeffery, J. (Ed.), Oxford University Press, Oxford, England.

Etienne, A., Berlie, J., Georgakopoulos, J., Maurer, M., 1998. Role of Dead Reckoning in Navigation. In: Healy, S. (Ed.), Oxford University Press, Oxford.

Golledge, R.G., 1999. Human wayfinding and cognitive maps. In: Gulledge, R.G. (Ed.), The Johns Hopkins University press, Baltimore, MD.

Gould, T., Dao, D., Kovacsics, C., 2009. The Open Field Test. In: Gould, T.D. (Ed.), Humana Press.

Graham, P., Fauria, K., Collett, T., 2003. The influence of beacon-aiming on the routes of wood ants. J. Exp. Biol. 206, 535.

Hartley, T., Trinkler, I., Burgess, N., 2004. Geometric determinants of human spatial memory. Cognition 94, 39–75.

Hecht, L., 1988. Mysterium microcosmicum: the geometric basis for the periodicity of the elements. 21st Century Sci., 18.

Hermer, L., Spelke, E., 1994. A geometric process for spatial reorientation in young children. Nature 370, 57–59.

Hoffmann, G., 1983. The search behavior of the desert isopod Hemilepistus reaumuri as compared with a systematic search. Behav. Ecol. Socio. 13, 93–106.

Hölscher, C., Tenbrink, T., Wiener, J.M., 2011. Would you follow your own route description? Cognitive strategies in urban route planning. Cognition 121, 228–247.

Hupbach, A., Nadel, L., 2005. Reorientation in a rhombic environment: no evidence for an encapsulated geometric module. Cognit. Dev. 20, 279–302.

Jeanson, R., Blanco, S., Fournier, R., Deneubourg, J., Fourcassie, V., Theraulaz, G.A., 2003. model of animal movements in a bounded space. J. Theor. Biol. 225, 443–451.

Joye, Y., 2011. A review of the presence and use of fractal geometry in architectural design. Environ. Plan. B: Plan. Des. 38 (5), 814–828.

Kelly, D.M., Bischof, W.F., 2008. Orienting in virtual environments: how are surface features and environmental geometry weighted in an orientation task? Cognition 109, 89–104.

Kelly, J.W., McNamara, T.P., Bodenheimer, B., Carr, H.T., Rieser, J. J., 2008. The shape of human navigation: how environmental geometry is used in maintenance of spatial orientation. Cognition 109, 281–286.

Keys, D., 2000. Catastrophe: an Investigation into the Origins of the Modern World. Arrow, London.

Koseoglu, E., Onder, D.E., 2011. Subjective and objective dimensions of spatial legibility. Procedia Soc. Behav. Sci. 30, 1191–1195. http://dx.doi.org/10.1016/j.sbspro.2011.10.231.

Lee, S.A., Shusterman, S., Spelke, E.S., 2006. Reorientation and landmark-guided search by young children: Evidence for two systems. Psychol. Sci. 17, 577–582.

Lee, S.A., Sovrano, V.A., Spelke, E.S., 2012w. Navigation as a source of geometric knowledge: Young children's use of length, angle, distance, and direction in a reorientation task. Cognition 123 (1), 144–161. http://dx.doi.org/10.1016/j.cognition.2011.12.015.

Lynch, K., 1960. The Image of the City. MIT Press, Cambridge.

MacInnis, D.J., Price, L.L., 1987. The role of imagery in information processing: review and extensions. J. Consum. Res. 13, 473–491.

Magliano, J.P., Cohen, R., et al., 1995. The impact of a wayfinder's goal on learning a new environment: Different types of spatial knowledge as goals. J. Environ. Psychol. 15, 65–75.

Nardini, M., Thomas, R.L., Knowland, V.C.P., Braddick, O.J., Atkinson, J., 2009. A viewpoint-independent process for spatial reorientation. Cognition 112, 241–248.

Payne, A., 1995. Advances in Relationship Marketing. Kogan Page, London.

Pratt, S., Brooks, S., Franks, N., 2001. The use of edges in visual navigation by the ant Leptothorax albipennis. Ethol. Socio. 107, 1125–1136.

Raubal, M., Winter, S., 2002. Enriching Wayfinding Instructions with Local Landmarks. In: Proceedings of the Second International Conference, GI Science 2002 Paper presented at the Geographic Information Science. Boulder, CO, USA.

Ruddle, R.A., Payne, S.J., Jones, D.M., 1999. The effect of maps on navigation and search strategies in very-larg-scale virtual environments. J. Exp. Psychol.: Appl. 5, 54–75.

Sacks, O., 2007. Karisini sapka sanan adam (A Man WHO Mistook His Wife for A Hat). YKY, Istanbul.

Sekaran, U., 2003. Research Methods for Business: A Skill Building Approach. John Wiley and Sons, New Jersey.

Shettleworth, S., Sutton, J., 2005. Multiple systems for spatial learning: dead reckoning and beacon homing in rats. J. Exp. Psychol. Anim. Behav. Process 31, 125–141.

Sheynikhovich, D., Arleo, A., 2010. A reinforcement learning approach to model interactions between landmarks and geometric cues during spatial learning. Brain Res. 1365, 35–47.

Sovrano, V., Bisazza, A., Vallortigara, G., 2005. Animals use of landmarks and metric information to reorient: effects of the size of the experimental space. Cognitive 97, 121–133.

Stanford, S., 2007. The open field test: reinventing the wheel. J. Psychopharmacol. 21, 134–135.

Steck, S.D., Mallot, H.A., 2000. The role of global and local landmarks in virtual environment navigation. Presence 9 (1).

Tashakkori, A., Teddlie, C., 1998. Mixed Methodology: Combining Qualitative and Quantitative Approaches. Sage, Thousand Oaks, CA.

Vargas, J.P., Portavella, M., Quintero, E., López, J.C., 2011. Neural basis of the spatial navigation based on geometric cues. Behav. Brain Res. 225, 367–372.

Vasquez, R., Ebensperger, L., Bozinovic, F., 2002. The influence of habitat on travel speed, intermittent locomotion, and vigilance in a diurnal rodent. Behav. Ecol. 13, 182–187.

Walsh, R., Cummins, R., 1976. The open field test: a critical review. Psychol. Bull. 83, 482–504.

Wang, R.F., Hermer, L., Spelke, E.S., 1999. Mechanisms of reorientation and object localization by children: a comparison with rats. Behav. Neurosci. 113, 475–485.

Yaski, O., Eilam, D., 2007. The impact of landmark properties in shaping exploration and navigation. Anim. Cogn. 10, 415–428.

Yaski, O., Portugali, J., Eilam, D., 2011a. City rats: from rat behavior to human spatial cognition in urban environments. Anim. Cogn. 14, 655–663.

Yaski, O., Portugalib, J., Eilama, D., 2011b. Arena geometry and path shape: When rats travel in straight or in circuitous paths? Behav. Brain Res. 225, 449–454. http://dx.doi.org/10.1016/j.bbr.2011.07.055.

Yaski, O., Portugali, J., Eilam, D., 2012. Traveling in the dark: the legibility of a regular and predictable structure of the environment extends beyond its borders. Behav. Brain Res. 229 (1), 74–81, http://dx.doi.org/10.1016/j.bbr.2011.12.043.

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