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Role of Cognition in Pedestrian-Level Universal Mobility: Case of Central Kolkata, India

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In this research, the role of cognition in Universal Mobility at the pedestrian-level has been investigated. A stretch of approximately 850 m in the core of Kolkata Municipal Corporation (in India) has been delineated as the case area for this research. The 02 data sets considered for this research are: 1) Physical data: Pedestrian Count and Vehicular Traffic Volume, and 2) Cognitive data: Light Intensity, Noise, and Thermal Comfort. The authors collected the data from the case area in the years 2020 and 2021. This paper initially involves determining the pedestrian "Level of Service" (LOS) based on the pedestrian count. Furthermore, the authors co-relate (Pearson's Correlation with a 95% confidence interval) the LOS data with the light intensity, sound intensity, and temperature data; to establish a relationship between them. The result of this research indicates that there is a gap in realizing the potential of walkability in the case area. The authors conclude that the improvement of cognition in pedestrian-level Universal Mobility can lead to a better physical environment for the specially-abled and elderly.

Introduction

There are 26.8 million specially-abled people in India as per the last census in 2011. Additionally, there are 103.8 million elderly people.[1] Along similar lines, the "United Nations Sustainable Development Goals" (UN-SDG) number 11 (Sustainable Cities and Communities) becomes more significant than ever in the Indian context. Universal Mobility is a fundamental component of "Sustainable Cities and Communities", which suggests equal mobility preferences for all,

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1. Social Statistics Division, Ministry of Statistics and Programme Implementation, *Disabled Persons in India - A Statistical Profile 2016* (New Delhi: Government of India, 2016).

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devoid of the users' physical conditions.[2] Pedestrian (including wheelchair-bound users) level use of urban areas is a relatively challenging domain of Universal Mobility in India. Specifically, in the old urban areas of India, the Universal Mobility scenario is more complicated due to organic urban development, low temporal changes, and high density. Amongst the numerous factors of pedestrian-level Urban Mobility, "Cognition" is significantly important. Cognition is important for specially-abled and elderly people alike since it (Cognition) ensures legibility, orientation, and a sense of place. Despite multiple international, national, and state-level guidelines related to Universal Mobility in India, the aspect of cognition has been disregarded in these guidelines. Although there has been immense research on accessibility and Universal Design in India, the impact of cognition on Universal Mobility at the pedestrian level of old Indian cities is a relatively new research topic.

Universal Mobility incorporates the needs of varied users, including the elderly and specially-abled within a designated spatial boundary. On an urban scale, Universal Mobility serves the function of an infrastructural bridge between buildings having Universal Design/Barrier-Free features and precincts with inclusive components. In addition to the previous statement, both inclusive buildings, and the inclusive precincts, shall remain non-utilitarian if they are not connected by a "Universally-designed" mobility corridor. Thus, Universal Mobility may be categorized as one of the top priorities in the United Nation's Sustainable Development Goal Number 11 which indicates "Sustainable Cities and Communities".[3] This paper focuses on Universal Mobility at the pedestrian level of old cities.

Pedestrian-level infrastructures in old cities are often affected by poor infrastructure and pose a threat to able-bodied and users with wheelchairs or walking assistance alike. Concerning this, a stretch in Central Kolkata (in India) is considered a case example for this paper. The typology of urban patterns is complex in old-core Indian cities (like Kolkata) due to the multiplicity of building uses, thus attracting users from a diverse age groups.[4] Age diversity presents a challenge to decision-makers regarding the type of facility in the pedestrian environment; on the other hand, it promotes the need for universal mobility[5]. Mahapatra, Mori, and Nomura (2021) establish that the challenges in implementing

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2. United Nations Department of Economic and Social Affairs, *Goal 11: Make Cities and Human Settlements Inclusive, Safe, Resilient and Sustainable* (United Nations Department of Economic and Social Affairs, 2015).

3. M. Brussel, M. Zuidgeest, K. Pfeffer, and M. v. Maarseveen, "Access or Accessibility? A Critique of the Urban Transport SDG Indicator," *International Journal of Geo-Information* (2019): 1-23.

4. G. D. Mahapatra, and K. Puntambekar, *Reinterpreting Urban Fabric in Cities with Living Heritage: The Case of Central Kolkata* (Delhi: COPAL Publishing Group, 2020).

5. Mahapatra, and N. Mandal, *Re-inventing Urban Spaces by Accessing Accessibility in Old City Core - A Case of Kolkata (*Chisinau: Lap Lambert Academic Publishing, 2019), 11-17.

Universal Mobility in an urban Indian context can be attributed to legislative as well as population density.[6] Old Indian cities are experiencing degeneration in terms of their urban fabric.[7] Since old cities are often associated with historic value, maintaining physical revitalization is also an added challenge for architects and city officials alike.[8] Furthermore, a unique assessment format is necessary for understanding the context-specific accessibility conditions of old core Indian cities.

The holistic approach to urban development should be to create a livable city and not mere infrastructural development.[9]Cognition, especially, plays an important role in improving the spaces of public use, including pedestrian spaces.[10] The importance of cognition is well-established in walkability, especially for elderly people. Additionally, mental maps are an effective form of cognitive perception of spaces; thus, serve as an essential tool for differently-abled and elderly.[11] In this context, pedestrians needed to be prioritized in the user group segment of the urban development. There are many definitions of a pedestrian. Besides regular walking by able-bodied people, pedestrian also includes people in a non-motorized wheelchair or, driving a motorized wheelchair with a speed of less than 10km/hr on the level ground.[12] Although international and national guidelines/goals encourage pedestrianization, poor urban-level pedestrian quality discourages pedestrian activity.[13]

This research paper is apportioned into three segments hereafter: 1) Analysis, 2) Major Findings, and 3) Proposals. 02 data sets are dealt with in the "Analysis" segment, they are a) Pedestrian Volume, and b) Cognitive Data (comprising Noise, Light, and Thermal Comfort Data). In "Major Findings", the following points are highlighted: a) Importance of Light in Cognition, b) Impact of Sound on

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6. Mahapatra, S. Mori, and R. Nomura, "Universal Mobility in Old Core Cities of India: People's Perception," *Sustainability* 13, no. 8 (2021): 1-36.

7. Mahapatra, K. Puntambekar, and S. Ckakraborty, "Understanding Transformation Dynamics in Old Cities," *Conscious Urbanism* 1, no. 1 (2021): 30-41.

8. S. Tiesdell, T. Oc, and T. Heath, "Towards the Successful Revitalization of Historic Urban Quarters," in *Revitalizing Historic Urban Quarters* (eds.) S. Tiesdell, T. Oc, and T. Heath, 200-212 (Oxford: Architectural Press, 1996).

9. Mahapatra, "Neighborhood Planning: Approach in Improving Livability and Quality of the Life in the Cities," in *Understanding Built Environment. Springer Transactions in Civil and Environmental Engineering* (eds.) F. Seta, A. Biswas, and J. Sen, 47-53 (Singapore: Springer, 2017).

10. R. Chopra, and Mahapatra, "Cognitive Mapping in Spaces for Public Use," *IJRET: International Journal of Research in Engineering and Technology* 7, no. 9 (2018): 138-142.

11. P. Gould, and R. White, *Mental Maps* (London: Allen and Unwin, 1986).

12. Roads and Traffic Authority NSW, *How to Prepare a Pedestrian Access and Mobility Plan - An Easy Three Stage Guide* (Sydney: New South Wales Government, 2002).

13. M. Taleai, and E. T. Amiri, "Spatial Multi-Criteria and Multi-Scale Evaluation of Walkability Potential at Street Segmnet Level: A Case Study of Tehran," *Sustainable Cities and Society* 31 (2017): 37-50.

Walkability, and c) Influence of Temperature on Mobility. In the last part of the paper "Proposals", the linkage between the five senses in humans and their pedestrian behavior and the roles of hormones in facilitating cognition in streetscape for specially-abled people, is mentioned. Additionally, the importance of Assistive Technology in achieving Service Level Benchmarks (hereafter, SLBs) is also discussed in the last leg of the paper. The details of the survey and the findings are mentioned hereafter.

Materials and Methods

The data collected by the authors in the case area for this research are 1) Pedestrian Volume and 2) Cognitive Data including Noise, Light Intensity, and Thermal Comfort. The locations where the data were collected along the study area are represented in Figure 1 and elaborated in Table 1 thereafter.

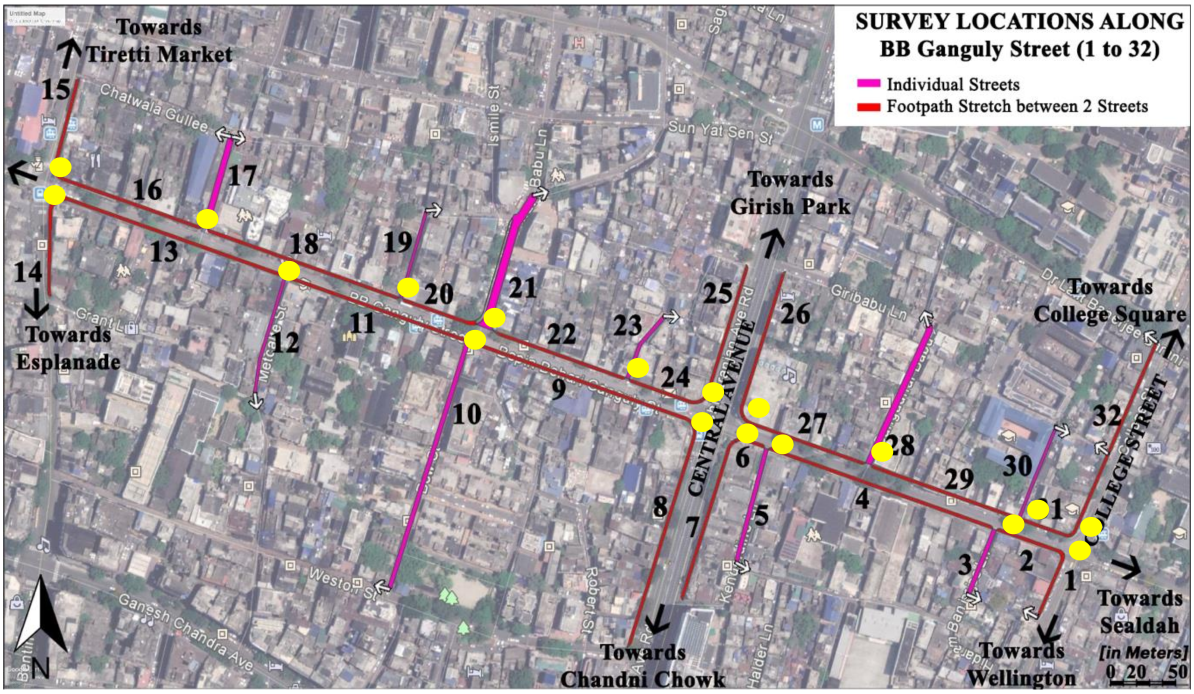


Figure 1. *Survey Locations*

The station points for the "Cognitive" survey were midway in some of the footpaths shown as number 1 to 32 as shown in Figure 1. The names of the footpaths selected (with corresponding footpath widths) for the survey are mentioned in Table 1. Furthermore, the station points for the "Pedestrian Volume" survey were done at the yellow points shown in Figure 1.

Table 1. *Name of Station Points for Survey*

Corresponding Numbers in Figure 1	Name of Station Points	Footpath Width
1	Nirmal Chandra Dey Street	2.1
3	New Bowbazar lane	5
5	Kenderdine Lane	3
7	Central Avenue (GATE 4: Yogayog Bhawan)	2.1
8	Central Metro (GATE 1: Indian Airlines)	2.1
10	Bow Street	3.8
12	Metcalfe Street	3.5
14	Bentinck Street	2.1
15	Rabindra Sarani Rd.	1.9
17	Chatawalla Gully	3.5
19	Phears Bye Lane	2
21	Phears Lane	4.8
23	Giri Babu lane	2.4
25	Central Metro (GATE 2: Lalbazar)	1.9
26	Central Avenue (GATE 3: RITES)	1.8
28	Gangadhar Babu lane	5
30	Bibi Rozio Lane	1.8
32	College Street	1.9

Pedestrian Volume [Peak Hour 15-Minute Interval]

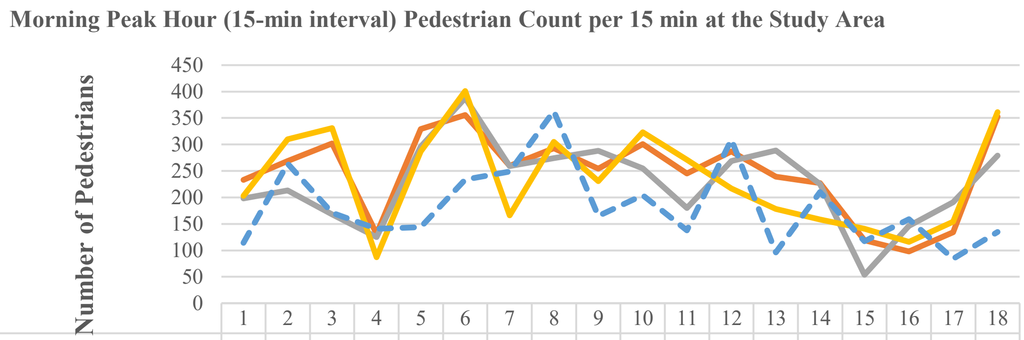
The peak-hour (15-minute interval) Pedestrian Volume Data were recorded three times in 2020 (on 25.10.2020, 14.10.2020, and 02.11.2020) and once in 2021 (on 24.09.2021). On each of the days, the data was recorded twice a day – at Morning Peak Hour (9:00 a.m. – 11:00 am) and Evening Peak Hour (6 p.m. – 7 p.m.). In the morning, the educational institutions and businesses begin functioning around 9 am. The offices start slightly later around 10 am. The educational institutions close around 2-4 pm. However, the offices and businesses start closing around 7 pm. This is also the time when a lot of informal shopping functions. Thus, depending on the mixed land use genre of the space, multiple peak hours are set for the survey. The format used for the Survey is mentioned in Table 2.

Table 2. *Survey format for Pedestrian Count*

Peak Hour Pedestrian Count Survey [15-minute interval]		
Date of Survey		
Time		
Name of the street		
Latitude and Longitude		
Width of the street		
	Pedestrians coming towards the surveyor	Pedestrians going away from the surveyor
Morning Peak Hour (-)		

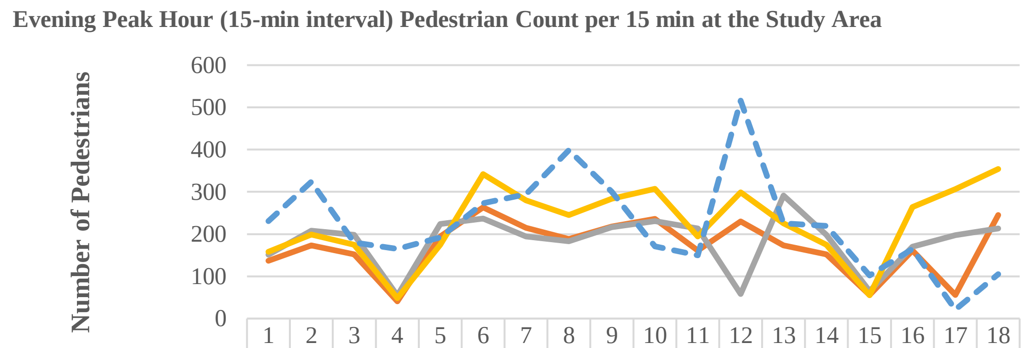
Evening Peak Hour (-)			
How many bicycles did you see during the survey?			
Did you see any differently-abled/ elderly people?			
Surveyed By:		*Checked By:*	

Figure 2 and Figure 3 represent the pattern of pedestrian traffic in the study area at morning peak hour and evening peak hour respectively.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Day 01 Morning Peak Hour	233	269	302	131	329	356	260	293	254	301	245	287	239	227	119	98	134	353
Day 02 Morning Peak Hour	198	213	168	125	296	388	259	274	288	255	180	269	289	225	54	146	191	279
Day 03 Morning Peak Hour	203	310	331	87	287	401	166	305	231	323	271	217	178	158	141	116	154	361
Day 04 Morning Peak Hour	114	264	171	141	144	234	249	363	165	204	138	309	96	210	117	159	84	135

Figure 2. *Morning Peak Hour (15-Min Interval) Pedestrian Count per 15 Minutes at the Study Area*



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Day 01 Evening Peak Hour	137	173	152	41	194	263	215	188	218	236	161	230	173	152	56	161	56	245
Day 02 Evening Peak Hour	151	208	198	54	224	237	194	183	216	231	213	58	291	198	65	170	197	213
Day 03 Evening Peak Hour	158	199	175	48	175	342	280	245	284	307	194	299	225	175	55	264	306	354
Day 04 Evening Peak Hour	231	324	180	165	192	273	294	399	300	171	150	516	225	219	102	165	21	105

Figure 3. *Evening Peak Hour (15-Min Interval) Pedestrian Count per Minute at the Study Area*

On average (mean value), the recorded Peak Hour (15-min interval) Pedestrian Count at the Study Area was 223 people in the morning and 201 people in the evening respectively. The average pedestrian flow in morning peak hours can be attributed to the presence of morning schools, offices, churches, and related informal vending during those hours. However, the flow is consistent during the evening due to the crowd returning from offices, shops, and informal vending too. Thus, nearly 800 pedestrians (derived by multiplying the "Peak Hours 15-minute interval Pedestrian Count" by four) commute through the study area during peak hours.

Cognitive Data

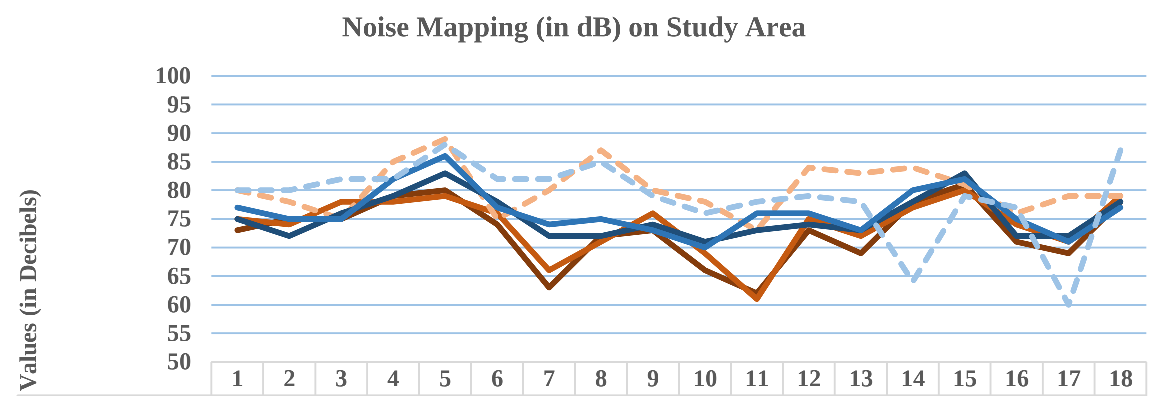
The next set of data for cognitive data involving noise, light intensity, and thermal comfort were recorded at the same time (peak hour) and date as the pedestrian volume survey. The data was recorded by the author using mobile-based applications.

Table 3. *Survey Format for Cognitive Data*

Cognitive Survey [Sound, Light and Temperature Data at Peak Hour]		
	Morning	Evening
Name of Surveyor		
Name of the street		
Date of Survey		
Time		
Sound Intensity (in Decibel)		
Light Intensity (in Lux)		
Temperature (in Degree Centigrade)		
	Checked By:	

Noise

Figure 4 illustrates the Noise (Sound Intensity in Decibel) in the Study Area. The data were recorded using "Sound Meter", a mobile-based application.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Day 1	73	75	75	79	80	74	63	72	73	66	62	73	69	78	81	71	69	78
Day 2	75	74	78	78	79	76	66	71	76	69	61	75	72	77	80	74	71	79
Day 3	80	78	75	85	89	75	80	87	80	78	73	84	83	84	81	76	79	79
Evening 1	75	72	76	79	83	78	72	72	74	71	73	74	73	78	83	72	72	78
Evening 2	77	75	75	82	86	77	74	75	73	70	76	76	73	80	82	75	71	77
Evening 3	80	80	82	82	88	82	82	85	79	76	78	79	78	64	79	77	60	87

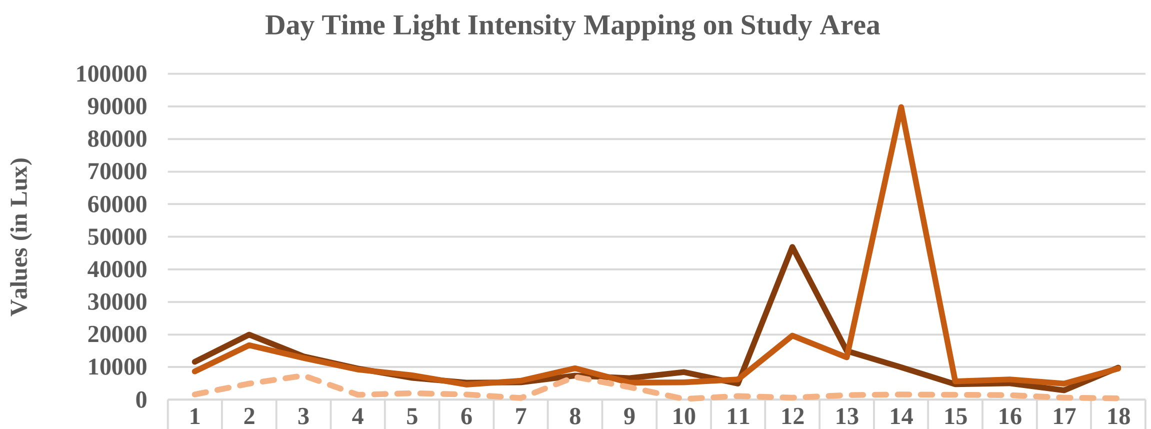
Figure 4. *Noise Mapping on Study Area*

Exposure over 85dB might lead to damage to hearing over prolonged exposure,[14] which has been observed in 04 out of 18 surveyed locations. The infrastructure and pedestrian environment need a more sensitive approach.

Light Intensity

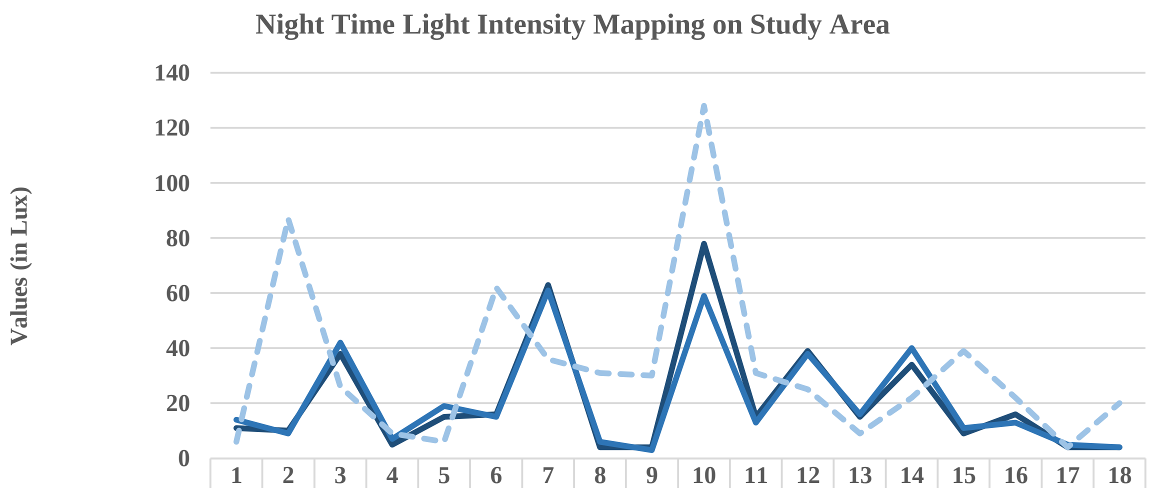
The Light Intensity (in Lux) in the Study Area during Day and Evening respectively are illustrated in Figure 5 and Figure 6. The data were recorded using a mobile-based application "Light Meter". The focus of this study was to understand whether the light intensity is satisfactory for people, especially during the evening/night.

14. National Center for Environmental Health. *What Noises Cause Hearing Loss?* (Centers for Disease Control and Prevention, 2019).



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Day 1	1157	1994	1328	9595	6720	5208	5310	7389	6585	8476	4900	4684	1496	9980	4769	5048	2880	9800
Day 2	8682	1675	1279	9211	7493	4687	5841	9606	5268	5340	6223	1967	1301	8982	5580	6209	4896	9506
Day 3	1636	4984	7414	1530	1986	1600	469	7016	3810	181	1073	636	1377	1565	1481	1394	589	463

Figure 5. *Day Time Light Intensity Mapping on Study Area*



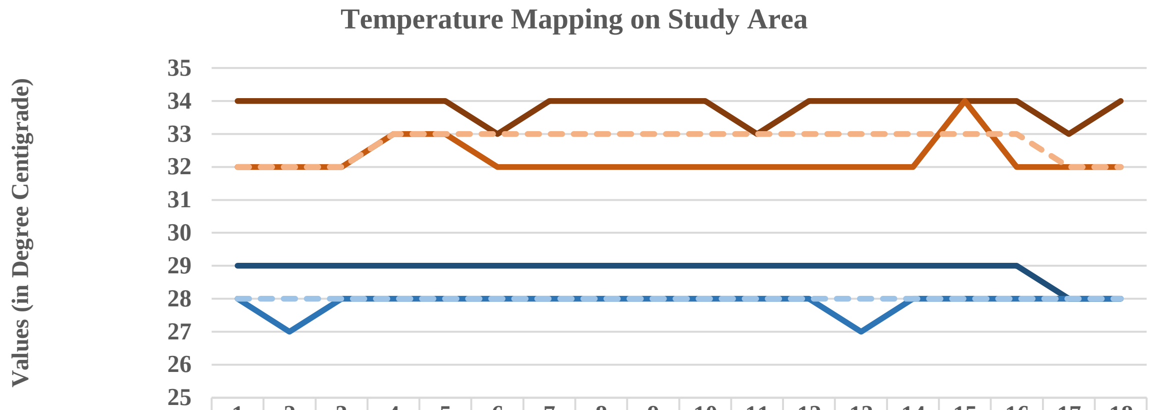
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Evening 1	11	10	38	5	15	16	63	4	4	78	15	39	15	34	9	16	4	4
Evening 2	14	9	42	7	19	15	61	6	3	59	13	38	16	40	11	13	5	4
Evening 3	6	87	26	9	6	62	36	31	30	128	31	25	9	22	39	22	4	20

Figure 6. *Evening Time Light Intensity Mapping on Study Area*

Despite having 93.75% of the streetlights in working condition (observed during the primary survey), instances show that there was >10lux illumination in certain pedestrian areas; thus, hinting towards a need for improved 'urban evening lighting'. The drastic differences in day and evening lighting create cognitive difficulties, especially for the elderly and differently-abled.

Thermal Comfort

The Temperature (in Degree Centigrade) in Study Area during Day and Evening respectively are illustrated in Figure 7. The data (in degrees Centigrade) were recorded using “Outside Temperature”, a mobile-based application. This study was conducted mainly to access the real-time situation of pedestrians.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Day 1	34	34	34	34	34	33	34	34	34	34	33	34	34	34	34	34	33	34
Day 2	32	32	32	33	33	32	32	32	32	32	32	32	32	32	34	32	32	32
Day 3	32	32	32	33	33	33	33	33	33	33	33	33	33	33	33	33	32	32
Evening 1	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28	28
Evening 2	28	27	28	28	28	28	28	28	28	28	28	28	27	28	28	28	28	28
Evening 3	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28

Figure 7. *Temperature Mapping on Study Area*

Although there is a minimal difference in day and evening temperatures during the surveyed dates, the actual scenario might be different. In summer, the temperature in Kolkata rises to 44 °C, complemented by 83% humidity: making the non-shadowed areas extremely uncomfortable. Besides, there are considerations like Apparent Temperature, Sensation and Perception, Time Required to feel the temperature change, Cardinal Direction, and “Felt” Temperature.

The aspects of light, sound, and temperature are related to the senses of vision, hearing, and touch, which need to be complemented with smell (landscape maybe) to create an enhanced cognitive experience.

Results

This section discusses two major things- 1) Criticism of the level of service based on the pedestrian data, and 2) Correlating various attributes of the field survey.

Criticism on the Level of Service

As per the Indian Road Congress (hereafter, IRC) guidelines, pedestrian areas in India must abide by certain ideal guidelines. IRC defines Level of Service (hereafter, LOS) using the "Pedestrian Space" method, which follows the formula: Pedestrian Space = Area / Peak Hour Volume. As per IRC, there is another way of calculating LOS using the "Flow Rate" method, which involves the formula: Pedestrian Unit Flow Rate = Peak 15-min Flow Rate/ (15 x Effective Walkway Width). However, for this paper, the "Pedestrian Space" method is being used, where:

Pedestrian Space = Area of Footpath/ Peak Hour Volume

Besides, the LOS thus determined is designated as LOS A, LOS B, LOS C, LOS D, LOS E, and LOS F, with LOS A being the best. The detail of the LOS is mentioned in Table 4.

Table 4. *Level of Service (Source: Guidelines for Pedestrian Facilities-IRC 103-2012, Indian Road Congress)*

S. No	Level of Service (LOA)	Pedestrian Space (area/peak hour volume)	Flow Rate (peak pedestrian flow rate/ effective walkway width)	Pedestrian Condition
1	LOS A	> 4.9	< 12	Ideal Pedestrian Condition
2	LOS B	> 3.3 - 4.9	< 12 – 15	Acceptable
3	LOS C	> 1.9 - 3.3	< 15 – 21	Just Satisfactory
4	LOS D	> 1.3 - 1.9	< 21 - 27	Poor
5	LOS E	> 0.6 - 1.3	< 27 – 45	Unsuitable
6	LOS F	< 0.6	Varying	Severely Restricted

[N.B.: The 'width' is footpath width and is calculated in meters; and the 'area' signifies footpath area (width x length) and is calculated in square meters.]

After interpreting the data collected during the survey in the case area, only seventeen out of the eighteen footpath stretches have LOS F or severely restricted pedestrian conditions. The one remaining footpath stretch is bearing the tag of LOS E or unsuitable pedestrian conditions. Thus, none of the footpath stretches have ideal/acceptable/satisfactory pedestrian conditions as per the guidelines laid by IRC. Tables 3 and 4 represents the LOS for each of the eighteen surveyed footpath stretches during the morning and evening peak hours. The following abbreviations are used in Tables 3 and 4:

W_E	=	Effective Walkway Width	(in m)
L_E	=	Effective Walkway Length	(in m)
A_E	=	Effective Walkway Area	(in m)
V_{15}	=	Peak 15-min Flow Rate	(in p)
V_{60}	=	Peak Hour Flow Rate	(in p)
PS_D	=	Daytime Pedestrian Space Value	(in sqm/ p)
PS_N	=	Daytime Pedestrian Space Value	(in sqm/ p)

The W_E and L_E data were collected during the primary survey. A_E was calculated thereafter. V_{15} has been derived by taking the average of the Peak Hour (15-min interval) Pedestrian Count for the morning peak hour and evening peak hour respectively. V_{60} was determined by multiplying V_{15} by 4. PS_D and PS_N have been calculated by dividing the A_E by V_{60}. The data has been elaborated in Table 5, and Table 6 respectively.

Table 5. *Level of Service at Morning Peak Hour*

MORNING TIME: Determining Quantitative Level of Service (LOS) through PEDESTRIAN SPACE METHOD							
Street Name	**W_E**	**L_E**	**A_E**	**V_{15}**	**V_{60}**	**PS_D**	**Corresponding LOS**
Nirmal Chandra Dey Street	2.1	51.49	108.13	187	748	0.14	**LOS F**
New Bowbazar lane	5.0	51.68	258.40	264	1056	0.24	**LOS F**
Kenderdine Lane	3.0	87.62	262.86	243	972	0.27	**LOS F**
Central Avenue (GATE 4_Yogayog Bhawan)	2.1	126.43	265.50	121	484	0.55	**LOS F**
Central Metro(GATE 1_Indian Airlines)	2.1	176.77	371.22	264	1056	0.35	**LOS F**
Bow Street	3.8	26.84	101.99	345	1379	0.07	**LOS F**
Metcalfe Street	3.5	89	311.50	234	934	0.33	**LOS F**
Bentick Street	2.1	72.04	151.28	309	1235	0.12	**LOS F**
Rabindra Sarani Rd.	1.9	72.37	137.50	235	938	0.15	**LOS F**
Chatawalla Gully	3.5	70.94	248.29	271	1083	0.23	**LOS F**
Phears Bye Lane	2.0	66.03	132.06	209	834	0.16	**LOS F**
Phears Lane	4.8	57.85	277.68	271	1082	0.26	**LOS F**
Giri Babu lane	2.4	54.62	131.09	201	802	0.16	**LOS F**
Central Metro (GATE 2_Lalbazar)	1.9	110.67	210.27	205	820	0.26	**LOS F**
Central Avenue (GATE 3_RITES)	1.8	115.52	207.94	108	431	0.48	**LOS F**
Gangadhar Babu lane	5.0	109.26	546.30	130	519	1.05	LOS E
Bibi Rozio Lane	1.8	72.5	130.50	141	563	0.23	**LOS F**
College Street	1.9	163.12	309.93	282	1128	0.27	**LOS F**

Table 6. *Level of Service at Evening Peak Hour*

EVENING TIME: Determining Quantitative Level of Service (LOS) through PEDESTRIAN SPACE METHOD							
Street Name	**W_E**	**L_E**	**A_E**	**V_{15}**	**V_{60}**	**PS_N**	**Corresponding LOS**
Nirmal Chandra Dey Street	2.1	51.49	108.13	169	677	0.16	**LOS F**
New Bowbazar lane	5.0	51.68	258.40	226	904	0.29	**LOS F**
Kenderdine Lane	3.0	87.62	262.86	176	705	0.37	**LOS F**
Central Avenue (GATE 4_Yogayog Bhawan)	2.1	126.43	265.50	77	308	0.86	**LOS F**
Central Metro(GATE 1_Indian Airlines)	2.1	176.77	371.22	196	785	0.47	**LOS F**
Bow Street	3.8	26.84	101.99	279	1115	0.09	**LOS F**
Metcalfe Street	3.5	89	311.50	246	983	0.32	**LOS F**
Bentick Street	2.1	72.04	151.28	254	1015	0.15	**LOS F**
Rabindra Sarani Rd.	1.9	72.37	137.50	255	1018	0.14	**LOS F**
Chatawalla Gully	3.5	70.94	248.29	236	945	0.26	**LOS F**
Phears Bye Lane	2.0	66.03	132.06	180	718	0.18	**LOS F**
Phears Lane	4.8	57.85	277.68	276	1103	0.25	**LOS F**
Giri Babu lane	2.4	54.62	131.09	229	914	0.14	**LOS F**
Central Metro (GATE 2_Lalbazar)	1.9	110.67	210.27	186	744	0.28	**LOS F**
Central Avenue (GATE 3_RITES)	1.8	115.52	207.94	70	278	0.75	**LOS F**
Gangadhar Babu lane	5.0	109.26	546.30	190	760	0.72	LOS E
Bibi Rozio Lane	1.8	72.5	130.50	145	580	0.23	**LOS F**
College Street	1.9	163.12	309.93	229	917	0.34	**LOS F**

For a day as well as evening in the eighteen surveyed stretches in the case area, none of them have Level of Service A or B or C or even D. Only one (5.6%) of the surveyed stretches have a LOS E which represents unsuitable pedestrian conditions. The remaining case area has LOS F which represents severely restricted pedestrian conditions.

Correlating Various Attributes of Field Survey

In this section of the paper, the pedestrian data is correlated with the other factors in this research- 1) Footpath width, 2) Noise, 3) Light intensity, and 4) Thermal comfort. Pearson's Correlation with a 95% confidence interval has been used in this research. Tables 5 and 6 elaborate on the correlation between Peak Hour Volume (15 min) and Variables in daytime and evening time, respectively.

Table 7. *Level of Service at Evening Peak Hour*

DAY TIME: Correlation between Peak Hour Volume (15 min) and Variables:			
S.No.	**Variable**	**Correlation Coefficient**	**Relationship**
1	Footpath Width (in Metres)	0.25	Weak +ve
2	Avg. Sound Intensity (in Decibel)	-0.07	Weak -ve
3	Avg. Light Intensity (in Lux)	0.11	Weak +ve
4	Avg. Temperature (in deg Centigrade)	-0.30	Weak -ve

Table 8. *Level of Service at Evening Peak Hour*

EVENING TIME: Correlation between Peak Hour Volume (15 min) and Variables:			
S.No.	**Variable**	**Correlation Coefficient**	**Relationship**
1	Footpath Width (in Metres)	0.44	Moderate +ve
2	Avg. Sound Intensity (in decibels)	-0.17	Weak -ve
3	Avg. Light Intensity (Average Day Time)	0.35	Moderate +ve
4	Avg. Temperature (in deg Centigrade)	-0.06	Weak -ve

In most urban areas with planned layouts and systematic transportation schemes, there exists a strong correlation between the pedestrian count and other related factors. However, in this research, there is an absence of a strong correlation between the pedestrian count and the other factors of the field survey.

Further Linking the LOS with Previous Research

However, research in the same case area involving 125 individuals (74 able-bodied people under the age of sixty and 51 people from the senior citizen and differently-abled people category) from the case area shows that the users are not comfortable with the pedestrian environment.[15] Only 74.51% of the respondents from the senior citizens and differently-abled categories can use the pedestrian facility, in comparison to 93.24% of the able-bodied people under the age of sixty. Furthermore, on inquiring the respondents (who use the pedestrian facility) about pedestrian comfortability using a Likert Scale approach (1 being the worst and 10

15. N. Ricci, *The Psychological Impact of Architectural Design* (Claremont, California: Claremont McKenna College, 2018).

being the best) the weighted mean score of their (senior citizen and differently-abled category) response was 4.92 out of 10, which is a poor score in terms of walkability standards. The response from able-bodied people under the age of sixty was also below satisfactory standards. The aforementioned research also reflects the lack of Universal Mobility standards in terms of infrastructure in the case area.

Thus, it can be inferred that although there is no correlation between the LOS and the pedestrian count; the full potential of the walkable population is not explored due to the lack of proper pedestrian facilities.

Discussion

At the urban level, design elements (like buildings, road patterns, or sculptures) can have both positive and negative effects on human psychology.[16] Pritzker Award (1980 edition) winning architects like Luis Barragan have emphasized the emotional aspect of design. Similarly, Indian architect Pramod Beri has put forward the theory of 'Form follows Feelings'. Additionally, the role of four out of five fundamental human senses: vision, touch, smell, and hearing influences pedestrian movement. Thus, in the wake of the 21st -century's global focus on Universal Mobility, Architectural Planning should take into consideration the parameters of design that could positively influence pedestrians by targeting specific hormonal secretions. The role of Assistive Technology can be crucial in this process.

The way human beings behave in a particular socio-environmental setting is based on the type and rate of hormones that they secrete.[17] The hormone plays an important role in the aging process too.[18] Even for differently-abled people, the hormonal aspects are comparatively more important since they are having compromised physical and/or mental states.[19] Hormones impact human behavior.[20] It can also influence the cognition of humans in different physical environments.[21]

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16. C. S. Carter, "Hormonal Influences on Human Behaviour," in *New Aspects of Human Ethology* (ed.) A. K. Schmitt, 141-162 (Boston, MA: Springer, 1996).

17. V. Zjačić-Rotkvić, L. Kavur, and M. Cigrovski-Berković, "Hormones and Aging," *Acta Clinica Croatica* 49 (2010): 549-554.

18. A. K. P. Kumar, "Hormones and Behaviour," in *Encyclopedia of Animal Cognition and Behavior* (ed.) S. T. J. Vonk, 1-22 (Cham: Springer, 2018).

19. Carter, "Hormonal Influences on Human Behavior," 1996.

20. A. Kumar, P. Kumar, M. Faiq, V. Sharma, K. Sesham, and M. Kulandhasamy, "Hormones and Behaviour," in *Encyclopedia of Animal Cognition and Behavior* (eds.) J. Vonk, and T. Shackelford (Cham: Springer, 2018).

21. R. R. Kearns, and R. Spencer. "An Unexpected Increase in Restraint Duration Alters the Expression of Stress Response Habituation," *Physiology & Behavior* 122 (2013): 193-200.

Stimulus is received by the brain when a person walks in an environment and accordingly the body responds, thus creating an associated memory leading to habituation. In contrast to the above, when a person walks in an environment that has a certain level of difficulty walking (like potholes, high sound of traffic, or poor visibility) a sense of fear is generated which leads to a sense of diminished security. The sense of fear is neurologically caused due to over-secretion of Epinephrine (Adrenalin and Cortisol) leading to an increased heart and breath rate.[22] In addition to this, the over-secretion of Epinephrine dilates the blood vessels in the lungs and muscles. Thus, specially-abled and elderly people often get disoriented and gets panicked when subjected to critical pedestrian conditions.[23] Architectural Planning Research can help human behavior by identifying and later influencing hormone secretion through architectural planning interventions.[24] Furthermore, the authors suggest that Assistive Technologies might prove beneficial for improving the behavior of the specially-abled and elderly in pedestrian environments.

Assistive Technology is essentially any technology or method to improve the daily life of specially-abled people.[25] The primary focus of assistive technology is to remove obstacles and foster the functional ability of a diverse user group.[26] Assistive Technology should be affordable and mandatory since it is considered a human right rather than a mere additional facility in the context of 21st-century urbanization[27]Although various assistive/ interactive technologies like HADRIAN, VERITAS, Inclusive CAD, SEE-IT, and the University of Cambridge fostered Inclusive Design Toolkit exist, their usage is highly dubious in the pedestrian

22. University of Rochester Medical Center Rochester, *Neuroscience* (University of Rochester Medical Centre, 2022).

23. L. B. Fich, M. Wallergård, A. M. Hansen, and P. Jönsson, "Stress Hormones Mediated by the Built Environment. A Possibility to Influence the Progress of Alzheimer's Disease?" in *ARCH 17: 3RD International Conference on Architecture, Research, Care and Helath* (eds.) N. Mathiasen, and A. Kathrine Frandsen, 150-162 (Kongens Lyngby: Polyteknisk Boghandel og Forlag, 2017).

24. World Health Organization and The World Bank, *World Report on Disability* (Malta: World Health Organization, 2011).

25. J. Mueller, M. Jones, and L. Broderick, "Assessment of User Needs in Wireless Technologies," *Assistive Technology* 17, no. 1 (2005).

26. L. d. Witte, E. Steel, S. Gupta, V. D. Ramos, and U. Roentgen, "Assistive Technology Provision: Towards an International Framework for Assuring Availability and Accessibility of Affordable High-Quality Assistive Technology," *Disability and Rehabilitation: Assistive Technology* 13, no. 5 (2018): 467-472.

27. E. Zitkus, "A Review of Interactive Technologies Supporting Universal Design Practice," in *Universal Access in Human–Computer Interaction. Design and Development Approaches and Methods*, 132-141 (Springer, Cham, 2017).

context of developing nations.[28] Additionally, street-level assistive technology focused on specific disabilities like the visually impaired or auditory impaired.

To foster the use of assistive technology at the street level, the authors have proposed further investigation in the same domain, which is mentioned hereafter.

Conclusions

For understanding the pedestrian behavior of the elderly alongside others, a simulation study is being conducted by the authors. In the first phase, the study involves 25 individuals from 16 different nationalities.

A survey format (shown in Table 9) was used to record the participants' data.

Table 9. *Survey Format for Understanding Pedestrian Behavior*

Survey Format for understanding pedestrian behavior						
Date of Survey						
Time						
Temperature (in degrees Centigrade)						
Wind Speed (in meter/second)						
Humidity (in %)						
Precipitation		YES		NO		
Snowfall		YES		NO		
Participant						
Name		Country			Age	
Gender	MALE		FEMALE		TRANSGENDER	
Travel Reading						
With a prosthetic suit	While going		seconds	While coming		seconds
Without a prosthetic suit	While going		seconds	While coming		seconds
Surveyed By:			Checked By:			

A footpath stretches of approximately 150 meters within the Hokkaido University campus between Seicomart and the Graduate School of Engineering (shown in Figure 8) was selected, and the participants were asked to casually walk up and down in that stretch. This stretch has a relatively higher pedestrian footprint in comparison to the other parts of the university. The participants were further made to walk the same stretch (up and down) wearing a geriatric simulator, which made them behave like elderly people.

Apart from other deductions, on average, the time taken by an individual in a simulated elderly condition is 2.11 times more than the time taken under an able-bodied condition.

28. C.-Y. Huang, C.-K. Wu, and P.-Y. Liu, "Assistive Technology in Smart Cities: A Case of Street Crossing for the Visually-Impaired," *Technology in Society*, 68, no. 101805 (2022): 1-8.

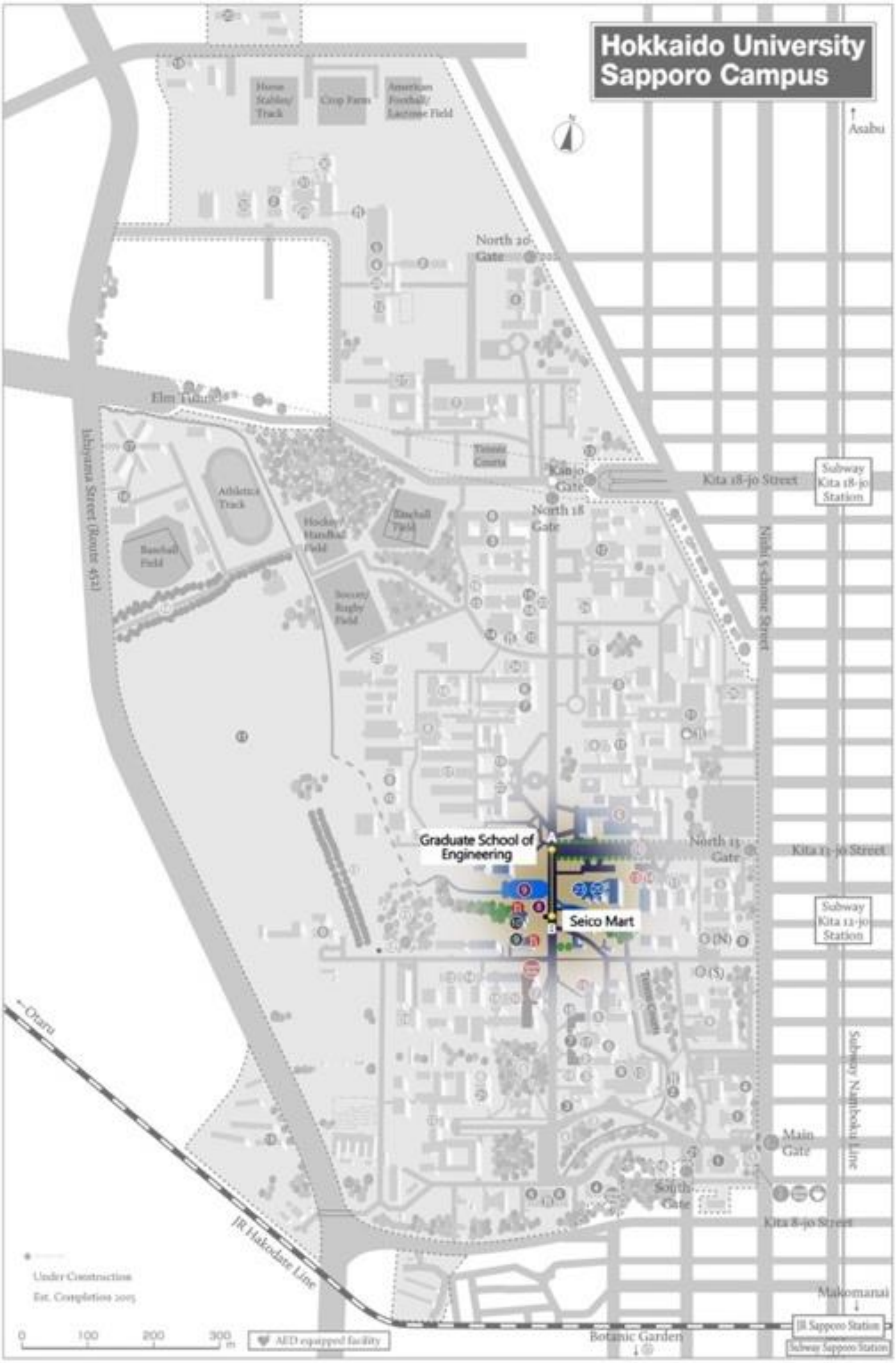
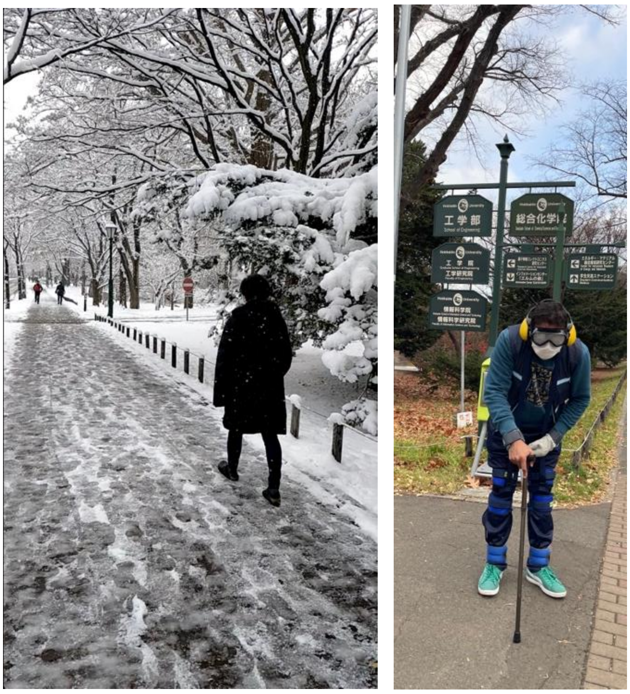


Figure 8. *Survey Location in Hokkaido University*
Source: Hokkaido University Official Website. https://www.global.hokudai.ac.jp/about/publications/campus-map/. [Accessed 28 April 2022.]

Figure 9 shows the different components that the geriatric simulator is composed of. Figures 10 and 11 show some pictures from the survey wearing the simulation suit and general conditions respectively.

Figure 9. *Simulation Suit*



Figures 10 and 11. *Pictures from Survey*

Apart from this, the authors are exploring the application of the Impairment Simulator Software developed by the researchers at the Engineering Design Centre in the Department of Engineering, University of Cambridge.[29] The software is used to generate alternate scenarios (like for differently-abled and elderly) and thereby open paths for strategic intervention.

Finally, the authors state that the methodological framework from this paper (results furnished in this paper and methodology for future research) shall be beneficial for researchers while designing/ planning for improving cognition in pedestrian-level Universal Mobility in other old cities of India.

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Bibliography

Brussel, M., M. Zuidgeest, K. Pfeffer, and M. v. Maarseveen. "Access or Accessibility? A Critique of the Urban Transport SDG Indicator." *International Journal of Geo-Information* (2019): 1-23.

Carter, C. S. Hormonal Influences on Human Behaviour. In *New Aspects of Human Ethology*, edited by A. K. Schmitt, 141-162. Boston, MA: Springer, 1996.

Chopra, R., and G. Das Mahapatra. "Cognitive Mapping in Spaces for Public Use." *IJRET: International Journal of Research in Engineering and Technology* 7, no. 9 (2018): 138-142.

Engineering Design Centre Department of Engineering, University of Cambridge. *Impairment Simulator Software*. Inclusive Design Toolkit, 2017. Available at: https://inclusivedesigntoolkit.com/simsoftware/simsoftware.html.

Fich, L. B., M. Wallergård, A. M. Hansen, and P. Jönsson. "Stress Hormones Mediated by the Built Environment. A Possibility to Influence the Progress of Alzheimer's Disease?" In *ARCH 17: 3RD International Conference on Architecture, Research, Care and Helath*, edited by N. Mathiasen, and A. Kathrine Frandsen, 150-162. Kongens Lyngby: Polyteknisk Boghandel og Forlag, 2017.

29. Engineering Design Centre Department of Engineering, University of Cambridge, *Impairment Simulator Software*. (Inclusive Design Toolkit, 2017).

Gould, P., and R. White. *Mental Maps.* 2nd Edition. London: Allen and Unwin, 1986.

Huang, C.-Y., C.-K. Wu, and P.-Y. Liu. "Assistive Technology in Smart Cities: A Case of Street Crossing for the Visually-Impaired." *Technology in Society,* 68, no. 101805 (2022): 1-8.

Kearns, R. R., and R. Spencer. "An Unexpected Increase in Restraint Duration Alters the Expression of Stress Response Habituation." *Physiology & Behavior* 122 (2013): 193-200.

Kumar, A. K. P. "Hormones and Behaviour." In *Encyclopedia of Animal Cognition and Behavior,* edited by S. T. J. Vonk, 1-22. Cham: Springer, 2018.

Kumar, A., P. Kumar, M. Faiq, V. Sharma, K. Sesham, and M. Kulandhasamy. "Hormones and Behaviour." In *Encyclopedia of Animal Cognition and Behavior,* edited by J. Vonk, and T. Shackelford. Cham: Springer, 2018.

Mahapatra, G. D. "Neighborhood Planning: Approach in Improving Livability and Quality of the Life in the Cities." In *Understanding Built Environment. Springer Transactions in Civil and Environmental Engineering,* edited by F. Seta, A. Biswas, and J. Sen, 47-53. Singapore: Springer, 2017.

Mahapatra, G. D., & Mandal, N. *Re-inventing Urban Spaces by Accessing Accessibility in Old City Core - A Case of Kolkata.* Chisinau: Lap Lambert Academic Publishing, 2019.

Mahapatra, G. D., and K. Puntambekar. *Reinterpreting Urban Fabric in Cities with Living Heritage: The Case of Central Kolkata.* 1st Edition. Edited by T. Mitra. Delhi: COPAL Publishing Group, 2020.

Mahapatra, G. D., S. Mori, and R. Nomura. "Universal Mobility in Old Core Cities of India: People’s Perception." *Sustainability* 13, no. 8 (2021): 1-36.

Mahapatra, G. D., K. Puntambekar, and S. Ckakraborty. "Understanding Transformation Dynamics in Old Cities." *Conscious Urbanism* 1, no. 1 (2021): 30-41.

Mueller, J., M. Jones, and L. Broderick. "Assessment of User Needs in Wireless Technologies." *Assistive Technology* 17, no. 1 (2005).

National Center for Environmental Health. *What Noises Cause Hearing Loss?* Centers for Disease Control and Prevention, 2019. Available at: https://www.cdc.gov/nceh/hearing_loss/what_noises_cause_hearing_loss.html..

Ricci, N. *The Psychological Impact of Architectural Design.* Claremont, California: Claremont McKenna College, 2018.

Roads and Traffic Authority NSW. *How to Prepare a Pedestrian Access and Mobility Plan - An Easy Three Stage Guide.* Sydney: New South Wales Government, 2002.

Social Statistics Division, Ministry of Statistics and Programme Implementation. *Disabled Persons in India - A Statistical Profile 2016.* New Delhi: Government of India, 2016.

Taleai, M., and E. T. Amiri. "Spatial Multi-Criteria and Multi-Scale Evaluation of Walkability Potential at Street Segmnet Level: A Case Study of Tehran." *Sustainable Cities and Society* 31 (2017): 37-50.

Tiesdell, S., T. Oc, and T. Heath. "Towards the Successful Revitalization of Historic Urban Quarters." In *Revitalizing Historic Urban Quarters*, edited by S. Tiesdell, T. Oc, and T. Heath, 200-212. Oxford: Architectural Press, 1996.

United Nations Department of Economic and Social Affairs. *Goal 11: Make Cities and Human Settlements Inclusive, Safe, Resilient and Sustainable*. United Nations Department of Economic and Social Affairs, 2015.

University of Rochester Medical Center Rochester. *Neuroscience*. University of Rochester Medical Centre, 2022. Available at: https://www.urmc.rochester.edu/life-sciences-learning-center/resources-lessons/lessons/neuroscience.aspx.

Witte, L. d., E. Steel, S. Gupta, V. D. Ramos, and U. Roentgen. "Assistive Technology Provision: Towards an International Framework for Assuring Availability and Accessibility of Affordable High-Quality Assistive Technology." *Disability and Rehabilitation: Assistive Technology* 13, no. 5 (2018): 467-472.

World Health Organization and The World Bank. *World Report on Disability*. Malta: World Health Organization, 2011.

Zitkus, E. "A Review of Interactive Technologies Supporting Universal Design Practice." In *Universal Access in Human–Computer Interaction. Design and Development Approaches and Methods*, 132-141. Springer, Cham, 2017.

Zjačić-Rotkvić, V., L. Kavur, and M. Cigrovski-Berković. "Hormones and Aging." *Acta Clinica Croatica* 49 (2010): 549-554.