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Bold Headlines of Urban Eyescapes: A Computational Approach of Urban Mapping via Digital Surveying and Eye-Tracking Technologies

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***Abstract*—**The sensory stimuli from the urban environment are often distinguished as subtle structures that derive from experiencing the city. The experience of the urban environment is also related to the social relationships and memories that complete the 'urban eyescapes' and the way individuals can recall them. Despite the fact that the consideration of urban sensory stimuli is part of urban design, currently the account of visual experience in urban studies is hard to be identified. This article explores ways of recording how the senses mediate one's engagement with the urban environment. This study involves an experiment in the urban environment of the Copenhagen city centre, with 20 subjects performing a walking task. The aim of the experiment is to categorize the visual 'Bold Headlined Stimuli' (BHS) of the examined environment, using eye-tracking techniques. The analysis allows us to identify the Headlining Stimuli Process, (HSP) in the select urban environment. HSP is significantly mediated by body mobility and perceptual memories and has shown how urban stimuli influence the intelligibility and the recalling patterns of the urban characteristics. The results have yielded a 'Bold Headline list' of stimuli related to: the spatial characteristics of higher preference; the stimuli that are relevant to livability; and the spatial dimensions easier to recall. The data of BHS will be used in cross-disciplinary city analysis. In the future, these results could be useful in urban design, to provide information on how urban space affects the human activities.

***Keywords*—**Urban eyescape, bold headlined stimuli, eye-tracker, perceptual memories, livability, navigation.

I. Introduction

URBAN environments have always had some form of multi-disciplinary activities on micro and macro scales that could mediate spatial reaction configurations. It has been recommended that the basic idea for the interaction between people and their environment is a two-sided process. This includes the reciprocal interaction between material impacts and the process of shaping minds and the resulting sense of livability. Consistent with this statement is the finding that urban spaces, built environments, and spatial stimuli are hives of activity that create networks of trials and innovation, which will provide answers to today's and tomorrow’s challenges. These spatial-centric ideas seem to be intransient, as the work of designers and policy-makers of yesteryears show that a city should be adjusted to everyday life's alterations [1]. This adjustment should be structurally or aesthetically and ready to produce a sense of place and emotionally positive experiences. However, researchers observed the physical-structural aspects of the examined environment in general, as isolated aspects of urban life (unimodal approach) [1]. For many years what made an urban space livable (what Barker referred to as ‘synomorphy’) [2], and the reactions of its inhabitants to it have been studied separately whereas spatial characteristics related to urban space livability have been the focus of urban planners and designers, responses to them, and their health impact, have been addressed by cognitive researchers. This distinction between structure and the urban environment's experiential process exposed the naivete of a generation of planners trained in the construction disciplines whereas architects could not import the users' multisensory nature in the design process, cognitive scientists proposed an “environmental determinism” with a multiplicity of factors related to human emotions, perception, sensation of the space, physiological comfort, etc. [3].

The trajectory of urban research follows cross-disciplinary collaborations that could significantly shape it. The potential for work with cognitive professionals specializing in spatial interaction and senses has already been demonstrated. Wang and Spelke proposed a self-to-object relation that is updated whereas a user changes position in an object-to-object basis [4], [5]. Such studies try to observe the relationship of the users and several objects, the geometric shape of the environment and spatial relations, and the storing system of visual snapshots [5]. Models that include spatial variables answer questions for which urban planners and designers have had nothing but practical approaches in the past. Although the human experience of public spaces was quantified (in-lab conditions), there is a gap in the literature examining the impact of cognitive processes (in-real-time situations) on how we practice design. Seeking to fill this gap, this research will introduce a real-time experiment to quantify the factors that make a space more comfortable and livable. The investigation follows a methodology currently under development, aiming to explore the Bold Headlines Stimuli[1] [7] of the urban environment. It is an experimental methodology in the real environment, which evaluates human perception and investigates how the structure of the physical environment affects the navigation process and users' recalling ability. It

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[1]Bold Headline Stimuli will be an important consideration in human-urban environment interface design.

aims to explore the experience of the users in open public space using different trackers (GPS, eye-tracking glasses, 3D mapping, etc.) and new technologies for the subjective understanding of the examined area.

II. Methodology of Data Collection

This paper summarizes recent results related to the urban environment of Strøget Street in Copenhagen, from the perspective of the cognitive reactions of the users. The collection of data was conducted using three steps: an eye-tracking navigational process, a questionnaire, and a recalling process through a virtual 3D environment. Those steps together argue for the significance of a cognitive analytical model for the urban environment. The precise methodology and the detailed experimental procedure can be found in [6]. In general, the methodology aims at highlighting the spatial cohesion resulting from a combination of spatial structure, analysis of spatial relations, and subject's reactions during their integration with urban space [7].

A. Eye Tracking Data

Eye-tracking methods have been used to examine the belief that the form of a city leads to radical changes in social interaction and behavior [8], [9]. Eye-tracking data [10] provide a dynamic simulation in which physical stimuli, their physical and natural elements, and features, as well as their physical qualities (flexibility, place identity, variety) can instantly be connected to the observer's codes and patterns [11]. In our case, based on iMotion [12] software analysis, a comprehensive survey of heatmaps of the examined path, not only for each participant individually but also as a group, has been developed as in Figs. 1-4. For Fig. 2, darker areas indicate more attention, whereas lighter indicate less attention. The opposite appears in Figs.1 and 3. The original heatmaps were in color.

Fig. 1 Overall heatmap of all subjects for the starting point area

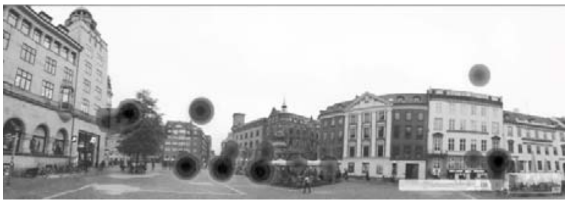

Fig. 2 Heatmap snapshot at the second minute of navigation of all subjects at the starting point area

Fig. 3 Overall heatmap of all subjects for the Holly Spirit church area

Fig. 4 Overall eye-tracking saccades record at the seventh minute of navigation of all subjects at the Holly Spirit church area

B. Questionnaire Data

A questionnaire enabled the second step of data collection. The questionnaire was divided into two sections: demographic data and semantic spatial data. The questions provide important information descriptors that could explain the multisensory perception in urban space. Tables I and II respectively list the demographics collected and semantic spatial data in the experiment. Pre-recording information for the path has been saved as key spatial data for the questionnaire and Table II. The examined path was characterized by 7 crossings, 9 intersections, 3 green zones, 62% white surfaces, whereas spotted areas given as options for answers where a. Copenhagen Court House, b. Nytorv Square, c. Strøget - Badstuestraede Crossing (1st Lego logo pic), g. Kongens Nytorv - Strøget Crossing, and h. Royal Danish Theater.

Table I presents the demographic data of subjects related to the first questions appeared in the questionnaire at the end of the eye-tracking process. Table II presents the semantic spatial data collected.

TABLE I
DEMOGRAPHIC DATA OF SUBJECTS

Subject ID	Gender	Age	Nationality	Living In	Education Level
R01	Female	25-35	Danish	Denmark	MSc
R02	Female	25-35	Cypriot	Italy	MSc
R03	Male	25-35	Rumanian	Denmark	MSc
R04	Female	25-35	Danish	Denmark	MSc
R05	Female	35-45	Rumanian	Rumania	MSc
R06	Female	18-25	Korean/ American	United States	BSc
R07	Female	25-35	French	France	MSc
R08	Male	18-25	German	Germany	High School
R09	Female	18-25	Cypriot	Cyprus	BSc
R10	Female	18-25	Cypriot	Cyprus	MSc
R11	Male	18-25	Korean	United States	High School
R12	Male	25-35	Dutch	Netherlands	High School
R13	Male	35-45	Turkish	Turkey	BSc
R14	Female	35-45	Dutch	Netherlands	PhD
R15	Female	35-45	Bulgarian	France	MSc
R16	Male	25-35	Cypriot	Cyprus	BSc
R17	Male	25-35	Egyptian	Germany	BSc
R18	Male	25-35	Finnish	France	BSc
R19	Male	18-25	Polish	Germany	BSc
R20	N/G	25-35	American	Canada	BSc

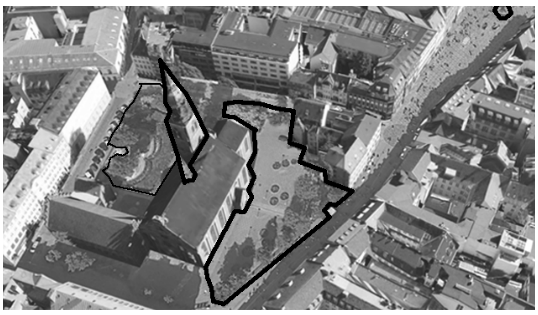

Fig. 3 (a) Mapping recalling elements in 3D environment by Subject R02

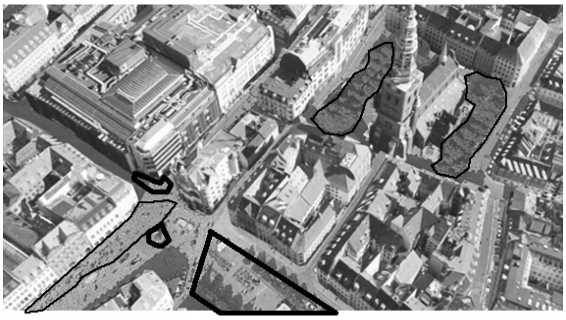

Fig. 3 (b) Mapping recalling elements in 3D environment by Subject R04

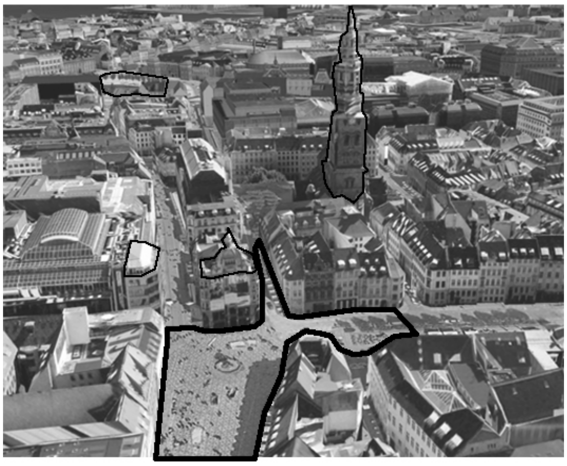

Fig. 3 (c) Mapping recalling elements in 3D environment by Subject R08

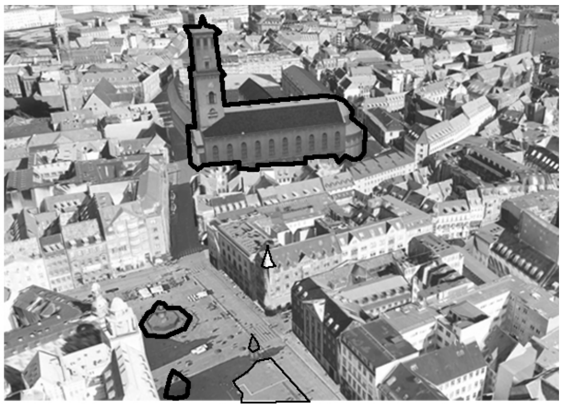

Fig. 3 (d) Mapping recalling elements in 3D environment by Subject R13

C. Recalling Process Data

The data in the final step of the process reveal an ongoing interest to researchers. A 3D environment appeared on the screen, whereas subjects got the instruction to underline the boundaries of elements that make the examined path more sustainable and livable. The final step's aim was twofold: Not only to investigate the relation between space and pre-recording memory, but also to examine the nature of the recalled elements. The recalled elements appeared to have a connection to subjects' haptic field of action (Greek: haptós “palpable,” haptikós, “suitable for touch”) in the transition from the real to the visual environment. Moreover, the collected data highlighted that optical reactions to the real did not refer to the visual. All the highlighted-recalled elements show the importance of daily activities of users in the urban environment providing how they have to emerge as significant priority factors of design (Figs. 3 (a)-(d) are mapping recalling elements in Stork Fountain and Holly Spirit church area given by multiple subjects).

TABLE II
RECALL DATA OF SUBJECTS

Subject ID	Crossings	Green Zones	Notes for crossings	Helpful Elements	White Surfaces Ratio	Colorful Surfaces Ratio	More Comfort Zone	?why?	More Stress Zone	?why?
R01	10	2	Lego& Burberry on the one with the foody smell and the one with the church.	Signs, Shadows near Gates	3/10	7/10	[c]	Signs easy to remember	[g]	Too open, dis-orientation
R02	16	1	Fountain, Illum Farewell point.	Signs	1/10	9/10	[b]	Familiar, Leave there	[a]	Too big space
R03	3	1	H&Ms Green zone.	Fountains, Signs, Plazas	3/10	7/10	[e]	Familiar	[a]	Too dark space
R04	7	3	The one with the colorful sub-path.	Similar Materiality	3/10	7/10	[e]	Multiple shapes, 360° angle view	[c]	Too touristic space
R05	3	0	The theater as landmark of the crossing.	Landmarks	6/10	4/10	[d]	Too high, easily spotted	[f]	Too crowded
R06	4	0	A baby girl was throwing a tantrum next a store. I swerved around a lot because too many people were walking along the center.	Signs, Traffic Signals, Brick Roads	1/10	9/10	[h]	Clearly see the end point	[b]	Too big space, Dis-orientation
R07	12	0	Nothing could be recalled.	Public flow	2/10	8/10	[d]	Easily Spotted	[f]	Zero interest
R08	2	2	Nothing could be recalled.	Public flow	3/10	7/10	[a]	Less traffic, more seats	[g]	Too Noise
R09	10	2	Bikes are too close to you.	Similar Facades	0/10	10/10	[e]	Open big space	[a]	Too Noise
R10	3	0	Smooth Edges – Fillet.	Pedestrian Path	2/10	8/10	[a]	not crowded	[g]	Too Narrow
R11	5	1	Houses Windows.	Tower, taller Buildings	4/10	6/10	[c]	Visibility	[a]	Unfamiliar scale
R12	4	5	Traffic lights waiting a lot.	Restaurants, Signs	5/10	5/10	[f]	Changes in width	[a]	Too big space
R13	5	1	Traffic lights visible from far away= changing navigation rhythm not to wait a lot.	Changes in the width of path	1/10	9/10	[d]	Food market	[e]	Awful Smell
R14	7	4	H&Ms Green zone, Toilet Smell in Fountain Square, where Crepes shop smell.	Smells, Angle views	0/10	10/10	[f]	Visibility	[d]	Too narrow path
R15	7	5	Illum crossing upper level someone coughing don't realize before that there was apartments there.	Skyline sculpture	3/10	7/10	[g]	Scale-Public Anxiety	[f]	Too much bikes minimize size of path
R16	3	10	Traffic lights waiting a lot.	Public flow	2/10	8/10	[a]	Cleaner	[h]	Can’t recall
R17	10	10	McDonald's cross construction missing surrounding need to look in plumbing floor.	Signs, Linear Path	2/10	8/10	[f]	Open Space	[g]	Too crowded
R18	5	3	Chinese people in H&Ms Crossing, just remember the one at the end with the concrete benches.	Smooth edges	1/10	9/10	[d]	Full view	[c]	Smells bad
R19	11	1	Green pots in 3rd one.	Angle view, Linear path	0/10	10/10	[e]	Not 90° edges	[d]	Too crowded
R20	6	3	Those with the benches welcoming you in the intersected path.	Similar Facades	0/10	10/10	[f]	Cleaner	[e]	Everyone can see you

III. HSP

The HSP encompasses the creation of lists related to the collected data, including analyzing the selected stimuli to identify their spatial characteristics. For this purpose, the process separates stimuli according to the duration of the fixation time on them (four categories of stimuli were identified: small, medium, large, and x-large scale). The separation aims to easier highlight patterns between spatial characteristics and the subject's reactions. Each fixation scale category gives specific variables related to an ontology describing the concepts involved in the urban design process, the spatial characteristics of the recalling livable stimuli, including structural patterns and navigation speed of subjects in the examined path. Combining those aspects of the process with the eye-tracking data composes the final level of the process. The main goal of the HSP is to establish a prototype for a spatial archive that will be developed using multidisciplinary data connected to the urban environment. Samples of data exported by the suggested process appear in Table III.

TABLE III
BHS

Subject ID	Fixation Scale (in ms)	Type of stimuli	Materiality	Average Speed in path (in km/h)	Max Speed in stimuli (in km/h)	Min Speed in stimuli (in km/h)
R01	Small (0-200)	benches	wood metal	4.70	5.00	4.20
	Medium (201-600)	sculpture skyline rooftop	stone brick		4.00	3.50
	Large (601-1000)	fountain	concrete water		6.50	5.00
	X-large (>1 sec)	crossroad	multiple *		7.40	6.50
R02	Small (0-200)	trees	wood	3.20	4.50	4.30
	Medium (201-600)	signs	metal glass		3.70	3.20
	Large (601-1000)	landmark	concrete glass		6.20	5.50
	X-large (>1 sec)	plaza	multiple *		7.20	6.80
R03	Small (0-200)	voids	concrete	4.30	4.40	4.20
	Medium (201-600)	sculpture skyline rooftop	stone brick		3.90	3.30
	Large (601-1000)	landmark	stone brick concrete		5.20	4.30
	X-large (>1 sec)	arcade	concrete glass		5.30	4.50
R04	Small (0-200)	public amenities	metal concrete	4.00	4.10	4.00
	Medium (201-600)	signs canteens	metal glass		3.70	3.40
	Large (601-1000)	landmark edges	concrete glass		6.20	6.00
	X-large (>1 sec)	edges	multiple*		6.60	6.20
R09	Small (0-200)	path alteration	multiple*	3.70	3.90	3.70
	Medium (201-600)	screens canteens	metal glass		3.80	3.60
	Large (601-1000)	plaza	multiple*		5.00	4.50
	X-large (>1 sec)	zebra crossing	concrete		5.10	4.90
R11	Small (0-200)	voids	wood	3.80	3.90	3.40
	Medium (201-600)	screens canteens	metal		3.60	3.00
	Large (601-1000)	arcade	wood metal		5.20	4.20
	X-large (>1 sec)	green turf	concrete		5.60	5.40
R12	Small (0-200)	people	-	3.60	3.70	3.30
	Medium (201-600)	edges	metal glass		3.50	3.20
	Large (601-1000)	landmark	stone brick concrete		4.20	4.00
	X-large (>1 sec)	crossroad	multiple*		5.50	5.20
R14	Small (0-200)	people	-	3.80	3.80	3.60
	Medium (201-600)	sculpture skyline rooftop	stone brick		3.60	3.20
	Large (601-1000)	arcade	concrete glass		5.10	4.80
	X-large (>1 sec)	plaza	multiple*		6.50	5.90
R15	Small (0-200)	sky	intangible	4.50	4.30	3.80
	Medium (201-600)	sculpture skyline rooftop	stone brick		3.70	3.20
	Large (601-1000)	landmark	stone brick concrete		6.10	4.50

Subject ID	Fixation Scale (in ms)	Type of stimuli	Materiality	Average Speed in path (in km/h)	Max Speed in stimuli (in km/h)	Min Speed in stimuli (in km/h)
	X-large (>1 sec)	edges	multiple*		7.50	5.80
R16	Small (0-200)	voids	concrete	4.80	4.00	3.50
	Medium (201-600)	edges	concrete glass		3.90	3.50
	Large (601-1000)	fountain	concrete water		5.40	4.20
	X-large (>1 sec)	darker areas	concrete		7.20	6.00
R17	Small (0-200)	people	-	3.20	3.50	3.20
	Medium (201-600)	screens signs	metal glass		3.10	3.00
	Large (601-1000)	green turf	glass		5.70	4.80
	X-large (>1 sec)	zebra crossings	concrete		6.40	5.10
R18	Small (0-200)	voids	metal concrete	3.60	3.60	3.50
	Medium (201-600)	moveable elements	concrete glass		3.20	3.10
	Large (601-1000)	fountain	glass		5.00	4.80
	X-large (>1 sec)	crossroad	concrete		5.10	4.50
R20	Small (0-200)	sky	intangible	4.20	4.20	3.50
	Medium (201-600)	moveable elements	metal		3.40	3.10
	Large (601-1000)	fountain	concrete water		5.80	4.60
	X-large (>1 sec)	darker areas	multiple*		6.60	4.20

IV. BHS

According to [13], Bold Headline Stimuli refers to spatial characteristics where the selection of response is directly related to the given stimulus's position. This research aims to extend this concept. It intends to include in the term the 'well-defined' spatial cues of the examined environment with a higher impact on the subjects' behavioral reactions. In other words, BHS is here defined as including the chosen spatial characteristics that evoke positive reactions characterized by variety and vitality, the sense of occurrence, nature (biophilic elements, scale, physical patterns), the silence and stillness (unplugged architecture that is allowing subjects to listen to their being), and the mobility and authenticity. The given stimulus's position is enriched, showing the multisided character of the designed elements of the urban environment.

Table III presents the natural characteristics of BHS collected from 10 subjects. The multiple* referred to various materials (concrete, stone, metal, plastic, glass, etc.) that subjects could recall but they were not confident to report them, whereas “-” referred to no recalled materials.

V. Discussion and Analysis

The research findings suggest that physical indexes and spatial characteristics significantly affect the conscious and unconscious responses of subjects. Based on the experiment results in Strøget Street, it should be noted that the optical reactions in stimuli (eye-tracking data) were not matched in the recalling process (questionnaire and virtual recalling in 3D environment). More precisely, only 10-15% of subjects could recall the ‘correct’ structure of the path related to crossings and green zones. Although the smaller-scale structural elements that were easier to spot during the navigation and orientation process were the most critical factors of livable space among citizens, only 20% could recall the type, color, and spatial characteristics of stimuli. The recalling process could be connected with the observation position and angle, since most of the observed stimuli have appeared above the average observation angle of stimuli (it seems that the average observation angle is about 28,5^{o}).

Research findings show that the physical stimuli spotted by subjects are significantly related to each other. Accordingly, to the physical flexibility of the stimulus, spatial livability is likely to increase. Highlighted stimuli are characterized by spatial cohesion, variety, visual penetrability, and flexibility. Therefore, although path identity in the eye-tracking process spotted some elements as crucial (biggest fixation scale, red areas in heatmaps), it seems that they are not bolded elements which subjects can easily recall due to the lack of specific spatial identity.

A relationship was found in the comparison of heatmaps and recalling tables. In the perception of livability, a relation between visual perception and visual memory was found. All the stimuli that appeared in the medium fixation scale (201-600 ms) were memorable visual stimuli observed in the average maximum speed of 3,65 km/h. Although the average maximum speed of observation had not many fluctuations between subjects, an inverse relationship was found in the immense observation speed (approximate to 6,25 km/h). This speed was related to X-large fixation scale stimuli (fixation time > 1 s). X-large fixation scale stimuli were hard to be recalled. Trying to interpret the results, the data suggest that the visual perception of highlighted stimuli is affected by the navigation speed.

The collected data gradually synthesized patterns of BHS, where eight variables appeared. The stimuli's nature was the most crucial spatial feature that subjects could easily recognize, integrated to the mobility (speed of navigation) and the sense of occurrence. Although the last one was automatically selected from subjects, it appeared as the essential variable in the understanding and recalling spatial stimuli through other senses except the visual. A synthesized pattern of BHS exported in this research appeared to highlight a connection between a spatial variation of the examined path, the scale of stimuli, and the haptic form of specific stimuli. Such patterns and connections emphasize the importance of the stimuli and not of the surrounding area. BHS leads to the understanding of the significance of the design environment to the way we perceive space.

VI. Conclusion

The present experimental process and the collected data provides evidence that the highlighted and recalled spatial data are eliminated when each variable that characterized them as BHS is assigned to separate response reactions. This investigation presents a methodology for collecting multiple types of data such as heatmaps, fixation points paths, recalling spatial mapping elements, speed of navigation, GPS position of subjects, and observation angles. The multisensory and multidisciplinary character of the experiment synthesizes a variety of data and a novel process of characterization of spatial stimuli related to other than the physical characteristics of each stimulus (Headline Stimuli Process). The archived in application results imply that patterns of biophysical measurements and physical metrics synthesized Bold Headline Stimuli patterns responsible for positive recalling impact in subjects.

In the future, the data analysis steps will be protocoled to guide strategies for design the future urbanization. Such strategies will help set production steps for well-being urban environments, appropriate for better orientation and livable spaces. Additionally, the resulting FUMapp will be finalized to yield an enclosing archive of quantitative and qualitative BHS patterns.

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Maria Christofi was born in Nicosia, Cyprus in 1989. Christofi is currently a Ph.D. candidate in Cognitive and Computational Architecture in the National Technical University of Athens (NTUA), while she holds a BSc in Architecture and DipArchEng from University of Cyprus (UCY), and a MSc in Space-Design/ Cognitive Architecture from NTUA.

Her recent research explores the intersections between architecture, cognition, and computing. She investigates how our environment's perception adapts to the alterations of the built environment. Her methodology is based on a situated computing practice that investigates spatial-cognitional phenomena across different scales. As a researcher, she has collaborated with Augmented Cognition Lab (AAU), MesArch Lab (UCY), National Technical University of Athens, University of Cyprus, and Franklin and Marshall University. Samples of her work appeared through the papers: M. Christofi, M. Katsaros, S.D. Kotsopoulos, "Form follows brain function: a computational mapping approach," in *Procedia Manufacturing* vol.44, 2020, pp.108-115. M. Christofi, G. Plastiras, R. Elia, V. Tsiourtis, T. Theocharides, M. Katsaros, "Sensor synchronization for android spatial applications," in *2020, 13th Cyprus Workshop on Signal Processing and Informatics (CWSPI),* pp.6,17. and M. Christofi, G. Plastiras, R. Elia, V. Tsiourtis, T. Theocharides, M. Katsaros, "Flexible cities: a multisided spatial application of tracking livability of urban environment (Periodical style-Submitted for publication)," *ICCSAD 2020: 14. International Conference on Computational Simulation and Architectural Design*, submitted for publication.

Christofi is a registered architect in the EU since 2013 and have several years of experience in architecture practice. During her studies received the Athanasios Ktorides Foundation Fellowship, the Sylvia Ioannou Fellowship, the Cyprus State Scholarship Foundation Fellowship, the DOMES International Magazine Award, and the International Allplan Young Architects Award.

Luis Emilio Bruni is a recognized expert in bio-cognitive semiotics with expertise in psychophysiology, media cognition, multimodal perception, and cultural dynamics. Bruni holds a Ph.D. in Molecular Biology and Theory of Science from the Institute of Molecular Biology, University of Copenhagen, Denmark, a Master of Science in International and Global Relations from the Universidad Central de Venezuela, and a Bachelor of Science in Environmental Engineering from the Pennsylvania State University, USA.

Since 2004, he is at Aalborg University (Denmark) where he is associate professor at the Department of Architecture, Design and Media Technology and directs the "Augmented Cognition Lab", dedicated to the study of perception, cognition, affective states and aesthetic experience in relation to immersive media and cognitive technologies. Currently, his research includes among other things narrative cognition in mixed reality systems.

Between 2011 to 2017, Dr. Bruni was elected for three consecutive periods as president of the Nordic Association for Semiotic Studies (NASS). In 2005, he was founder member of the International Society for Biosemiotic Studies (ISBS), and currently serves in its executive committee. He serves in the Board of the Association for Research in Digital Interactive Narratives (ARDIN) and in the Board of the International Society for Information Studies (IS4IS).