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OWNER
Prof. Dr. Kemal Kutgün EYÜPGİLLER
Istanbul University, Faculty of Architecture, Istanbul, Turkiye

RESPONSIBLE MANAGER
Prof. Dr. Kemal Kutgün EYÜPGİLLER
Istanbul University, Faculty of Architecture, Istanbul, Turkiye

CORRESPONDENCE ADDRESS
Istanbul University, Faculty of Architecture,
Süleymaniye Mahallesi Besim Ömer Paşa Caddesi No: 7 34116 Fatih, Istanbul, Turkiye
Phone: +90 (212) 440 02 40 (Ext: 14390)
E-mail: jtadp@istanbul.edu.tr
https://iupress.istanbul.edu.tr/en/journal/jtadp/home

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About the first issue

This is the first issue of the Journal of Technology in Architecture Design and Planning (JTADP), an interdisciplinary, technology-oriented journal devoted to the promotion of knowledge and debate on architecture, design, and planning. JTADP is the first peer-reviewed, international academic journal of the Istanbul University Faculty of Architecture, and its Editorial Board consists of researchers from various countries and various fields related to technology, architecture, design, and planning.

With such a multi-faceted set-up, JTADP's scope may need to be elucidated in order to inform prospective contributors and quality-concerned readers about what to expect. Because technology is defined as a process that covers the transformation and use of basic and applied sciences' data into production within creative processes and the analysis of their social effects, technology naturally constitutes the essence of architecture, design, and planning activities. The fact that technology occurs as a process in all kinds of design activities emphasizes the organic and inseparable unity these three aforementioned fields and their sub-headings have with technology. Technology, and therefore architecture, design, and planning, involve creativity and intelligence being combined with science, art, engineering, economics, and social studies in order to increase the quality of human life. The point one should note here is that technology is not only related to science and engineering. It is also a reflection of fields such as art, sociology, psychology, and economics. Because the dimensions of technology have not been adequately addressed in scientific publications in the fields of architecture, design, and planning, the decision has been made to have JTADP focus on these issues with the aim of exploring the interfaces among design, architecture, and planning and their practical applications.

Many people contributed to the preparation of the first issue of JTADP. First and foremost, we would like to thank Prof. Dr. Gülen Çağdaş, who accepted our invitation to have her as the editor of the first issue and has made important contributions with her valuable publishing experience. We would like to thank Gülce Kırdar, who had supported Prof. Dr. Çağdaş, as an assistant guest editor. This first issue would not have been possible without the support and hard work of Istanbul University Press. We would like to thank Istanbul University Press General Operations Manager Dr. Metin Tunç, operations chief Esma Çavuşoğlu and operation assistants Özgür Özdemir and Selin Dizbay for their assistance and guidance.

This first issue of the journal has 6 research articles. We would like to thank all the authors who responded to our call for papers and sent their work to JTADP, all the valuable researchers who accepted our call to referee, and Lecturer Elizabeth Mary Earl and Lecturer Rachel Elana Kriss from Istanbul University, who provided proofreading for the accepted articles.

JTADP is just at the beginning of its life. We believe that it will grow with the contributions ofvaluable researchers and be a platform for making important contributions to the academic world.

Prof. Dr. Kemal Kutgün EYÜPGİLLER, Editor-in-Chief
Assoc. Prof. Dr. Zeynep YAZICIOĞLU HALU, Co-Editor-in-Chief
Assist. Prof. Dr. Berrak KARACA ŞALGAMCIOĞLU, Co-Editor-in-Chief

Editorial

The subject for the Faculty of Architecture's first issue of the *Journal of Technology in Architecture, Design, and Planning* (*JTADP*) is decision support systems. The main objective of this issue is to discuss the use of computational approaches in architectural and urban studies.

Decision-making is a process that involves people's cognitive abilities in terms of learning, reasoning, and critical thinking. The goal is to make the most appropriate decision regarding complex or uncertain problems. In most cases, the decision-making process is based on the experience of an expert. This expert faces difficulties in changing conditions that require the support of computational systems. Decision Support Systems (DSSs) are systems that support experts regarding the cognitive process of decision-making. Different disciplines' use of DSSs to solve complex or ill-defined problems has become widespread in parallel with the developments in information, communication, and knowledge technologies. DSSs assist experts by offering alternatives using artificial intelligence that has been specialized for a particular problem. A DSS is a computer program that takes the relevant knowledge experts use as inputs to produce outputs for finding the solutions best suited to the problem.

The first category is data-driven DSS methods and encompasses techniques such as data mining, knowledge discovery in databases (KDD), Bayesian belief networks (BBN), and the analytical hierarchy process (AHP), as well as various statistical tools. These methods provide a solid foundation for extracting relevant information from large data sets and identifying patterns to aid in decision-making. The second category involves methods based on first-generation artificial intelligence (AI), which include knowledge-based systems, expert systems, and case-based reasoning approaches. These systems employ rule-based reasoning to assist in decision-making by drawing upon established knowledge and expertise to provide informed recommendations. Lastly, the third category comprises computational intelligent systems such as cellular automata, multi-agent systems, artificial neural networks, fuzzy logic, genetic algorithms, and swarm intelligence. These advanced techniques leverage cutting-edge computational intelligence paradigms, thus contributing to more effective decision support using optimization and simulation models. These methods form the basis for a wide array of DSSs, each tailored to specific use cases and decision-making scenarios, ultimately enabling enhanced decision-making processes in various disciplines.

The scope of the decision-making applications has a wide range in the urban, architectural, engineering, and design domains at different scale and for various topics such as regional and urban planning, land use planning, urban management, facility selection, transportation, environmental issues, structural issues, construction, interior design, industrial design, and evaluations. Within the scope of this issue, articles are expected that present different computational tools, technologies, methods, and applications for decision-making in different fields.

In this context, the first issue of *JTADP* discusses the use of DSSs with regard to their various usage possibilities in the architectural and urban research domains, their different computational methods and approaches, and their role in problem solving. The focus is on DSSs at the building scale, with a particular emphasis on how computational models are used for decision-making, before shifting to the urban scale and discussions on the role of optimization and simulation methods in decision-making.

The first section includes studies on DSSs at the building level through the use of computer models as a decision support tool. Alim BATTAL and Sevil YAZICI investigate the potential of Nitinol-based foldable facade systems for creating climate-adaptive structures. Their study transfers the foldable properties of Nitinol as a smart material into an algorithmic modelling environment using computational design and simulation tools, simulating responsive folding techniques and generating folding unit alternatives to develop a kinetic facade system. This system is composed of foldable units and aims to support sustainability decisions at the building scale. Their work highlights the significant contributions DSSs have in enhancing the sustainability of architectural practices through the innovative use of responsive folding techniques. İhsan Kasım KARATAŞ, Barış YILDIZLAR, and Barış SAYIN's study offers an insightful approach to assessing seismic performance in historic masonry buildings. Using a three-dimensional finite element (FE) model, they conduct a seismic performance analysis of the KLP Building at Istanbul University's Cerrahpaşa Campus with the aim of supporting safety decisions during restoration. This research underlines the pivotal role DSSs have in enhancing the seismic performance of historic masonry buildings while being restored.

The second section focuses on DSSs at the urban scale using optimization and simulation methods as a decision support tool. Merve Deniz TAK and Naime Hülya BERKMEN explore daily walking tour route potentials for visitors to the Historic Peninsula using the generative design method of single objective optimization as a decision support tool. This study considers site topography and road conditions, aiming to reveal the diverse route potentials within the peninsula's protected areas. By establishing nine distinctive sightseeing routes prioritizing walkability and immersion in historical texture, TAK and BERKMEN offer valuable support for travel decisions made by city planners, tour guides, and the travelers themselves. Next, Emirhan COŞKUN's research applies cellular automata in urban growth modelling through geospatial techniques using population and urban form attributes data to conduct a suitability analysis with a specific focus on the dense city of Istanbul. COŞKUN's analysis serves as a valuable decision support tool that facilitates a more comprehensive approach to urban policy-making and transformation.

In the third section, the studies by Emre İŞLEK and Mehmet Emin ŞALGAMCIOĞLU and by Gülce KIRDAR offer distinct but complementary perspectives on the intersection of technology and urban studies. İŞLEK and ŞALGAMCIOĞLU's study delves into the transformative impact Information and Communications Technologies (ICTs) have on architectural practices. Their study uses grounded theory methodology to analyze six case studies that have different ICT adaptation levels and workflows. Their research reveals how architects can hybridize their practice with new ICT technologies by considering the potentials and drawbacks of the constantly developing ICT habitat. This study offers crucial insights into the role of ICTs as a decision support tool facilitating change and innovation in architectural design processes. Gülce KIRDAR handles the use of decision support methods within big data in urban studies by conducting a systematic literature review. The author explores the use of big data in urban studies through selected state-of-the-art studies on urban informatics that utilize big data to support urban decision-making through exploratory research. The study underlines the trend in big data studies for urban planning and decision-making and emphasizes the pivotal role of data-driven computational and spatial statistical methods. This study aims to present the growing trend in big data studies for urban planning and decision-making.

As the guest editors for the first issue of the *Journal of Technology in Architecture Design and Planning*, we would like to express our sincere gratitude for being invited to the Dean, Prof. Dr. Kutgün EYÜPGİLLER. We hope this journal will be a platform for sharing information and discussions for academicians, researchers, and practitioners in this context.

Emeritus Prof. Dr. Gülen ÇAĞDAŞ, Guest Editor, Istanbul Technical University
Gülce KIRDAR, Assistant Guest Editor, PhD Student, Istanbul Technical University

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RESEARCH ARTICLE

The Use of Smart Materials in Architecture: Nitinol-based Foldable Façade Systems

Alim BATTAL[1] Sevil YAZICI[2]

[1]Fatih Sultan Mehmet Vakıf University, Faculty of Architecture and Design, Department of Architecture, Istanbul, Türkiye
[2]Istanbul Technical University, Faculty of Architecture, Department of Architecture, Istanbul, Türkiye

ABSTRACT
The built environment accounts for a significant portion of global energy consumption and carbon emissions. The generation of kinetic facade systems that can adapt to the changing environmental conditions has gained even more importance for this reason. This study focused on the use of shape memory alloys (SMA) and folding techniques to create heat-active systems and explores the potential of using smart materials in architectural design. The methodology of this research consists of two main stages as undertaking physical experiments and generating a computational design model of the system. Physical experiments involved shaping and programming Nitinol wire as a type of SMA, and creating foldable units based on flat and curved folding techniques. The computational design process includes transferring the physical behavior of Nitinol wire and foldable units by the use of design and simulation tools in an algorithmic modeling environment, in order to create a kinetic building envelope model. The study discusses the potential use of responsive folding techniques to create facade elements that can change shape through the use of SMA actuators without additional mechanical devices and energy use.

Keywords: Climate-adaptive façade, smart materials, shape memory alloy, folding

1. Introduction

Today, we confront difficult goals such as limiting global warming and the use of fossil fuels by maximizing energy efficiency. The built environment contributes significantly to the human carbon footprint, accounting for 30% of the global energy demand and 55% of global energy consumption. As the part of the building that connects to the outside world, the facade is a key part of how well the building uses energy (Schneider et al., 2020). For this reason, the evolution of facade systems that are responsive to environmental conditions has also acquired relevance. Innovative concepts such as "Adaptive Building Facades" will play a key role in the near future since the energy performance of buildings can be maximized through dynamic design (Ergin & Girgin, 2020). New generations of facade systems are becoming more flexible and multifunctional (Boer et. al., 2011). The research conducted by Fiorito et al. shows that using "smart materials" that can control themselves or make their own adjustments can help solve problems with overcomplicated designs, maintenance, and recycling for facade systems (Fiorito et al., 2016). Today, apart from a few groups of smart materials, which are divided into more than twenty groups, their use in architecture is still being researched. These materials contribute to the adaptation of buildings to environmental conditions with their unique behavior patterns. Shape memory alloys (SMA), which belong to the group of smart materials that alter shape and form in response to environmental stimuli, have the inherent capacity to perceive and directly adapt to changing environmental circumstances through a variety of motions.

Kinetic facade systems, which exhibits dynamic behavior against environmental conditions, contributes positively to the energy performance of buildings. However, traditional kinetic facade systems employ a large number of linked, movable components to achieve movement. But, facade systems that use SMAs as a component have the ability to move without any external elements or forces. This reduces the system's complexity and, most importantly, its energy consumption. Furthermore, the geometry of the elements that make up the system and the way they move are the main factors affecting energy consumption and efficiency. Various solutions are being sought to save the system from complexity and minimize the amount of energy. As a solution, the kinetic behavior of Origami geometries can reduce the overall amount of energy required for movement by the system. Due to the self-folding nature of Origami geometries and the shape memory behavior of certain alloys, it is possible to create a component for adaptable facade systems that does not require external force and energy. Combining smart materials such as SMA with different

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folding methods can produce unique solutions for kinetic or adaptable facade systems.

In recent years, kinetic facade systems have been a way to make interior spaces more comfortable by blocking the sun, controlling how much light gets in, and blocking out noise (Karaseva & Cherchaga, 2021). These systems are also responsible for energy consumption and the efficiency of buildings. However, today's built environment requires more innovative solutions to increase the energy efficiency of buildings. Smart facade systems that include intelligent and interactive elements present a new solution for kinetic facade design. According to this typology, a kinetic facade is a system that adjusts the geometry or position of the whole facade and/or its components in response to external inputs. (Boer et. al, 2011). Their ability to respond directly to environmental stimuli using little or no energy makes SMA-based facades advantageous over facade systems with mechanical control systems. Various facade designs have emerged that use SMAs as the system itself or as a subcomponent. Developed by Rift Architecture, the Air Flower project includes independent SMA- based components that provide air flow and temperature control without using electric energy. These components provide interior comfort by opening when the SMA reaches its activation temperature. With the reduction in temperature, the SMA-based components close and airflow stops (Payne & Johnson, 2013). Another project that uses SMAs as facade elements is Living Glass, conducted by S. Yang and D. Benjamin in 2005 The project uses electrical stimuli that activate SMAs to control the amount of CO2 in the interior. When the CO2 level reaches higher levels, the electrical stimuli activate SMAs to open facade elements. When the CO2 level of the interior is equal to that of the exterior, the SMAs return to their initial state by closing the facade elements (Ergin & Girgin, 2020). The Blind Project, developed by K. Khoo, F. Salim, and J. Burry, aims to create a media facade by embedding SMA springs beneath an elastic membrane with perforations like eyes (Khoo et. al., 2011). By investigating state-of-the-art works, this paper aims to contribute to the field by introducing alternatives for kinetic facade systems using combinations of different folding patterns and shape memory alloys.

By investigating state-of-the-art works, this paper aims to contribute to the field by introducing alternatives for kinetic facade systems using combinations of different folding patterns and shape memory alloys.

This study particularly focuses on the use of SMA and folding techniques to create heat-active facade systems. It also draws attention to the alternatives offered to kinetic facade systems by examining the combination of different folding patterns and shape memory alloys.

1.1. Shape Memory Alloys

The discovery of martensite in steel by Adens Martens in the 1890s was an important step towards the development of future shape memory alloys (Gamal & Mowafy, 2018). Although the first shape memory effect was observed in the Au-Cd alloy in the 1930s, the most important development occurred in 1962, when Buehler and Wang discovered the phase transformation and the associated shape memory effect in the Ni-Ti (Nitinol) alloy. Shape memory effect materials are preferred in many practical and advanced applications today. These materials are used in industrial and medical applications such as machinery, equipment, building materials, medical devices, and vehicles. They are also used in advanced applications such as electronic devices and spaceships. Moreover, a few projects, such as The Harvest Screens, AIR Flower, and the Flea Tower mentioned earlier, are architectural examples that use shape memory alloys in the building envelope.

Shape memory alloys and polymers are materials that have the ability to regain their original shape when heated after being deformed. SMA has shape memory and super elasticity. The shape memory effect is the ability of alloys to return to their original form (austenite phase) when heated to phase transformation temperatures. Super elasticity, on the other hand, is the property of returning to its original form after the load applied on it is removed (Figure 1) (Chu et al., 2012).

1.2. Nitinol as a Shape Memory Alloy

Nitinol, a shape memory alloy, was employed in this work to construct adaptable components in response to environmental stimuli due to its relatively rapid movement capabilities and low cost. These two qualities make it ideally suited for energy-efficient kinetic facade systems.

Nitinol is a group of intermetallic compounds based on nickel and titanium. Due to the thermoelastic martensitic transition, it exhibits shape memory and superelasticity (Wadood, 2016). The nitinol wires utilized in this research are flexible at room temperature, but when heated above the transition temperature, they return to their "recorded form" (Won et al., 2017). This change was used to create an actuator for adaptable movement. To save a specific shape, the Nitinol wire has to be fixed in the desired position and heated between 400 °C and 800 °C for around 5 minutes, then immediately cooled down (programming of Nitinol). The programmed wire can be deformed as desired, and then returned to the programmed shape with the activation temperature.

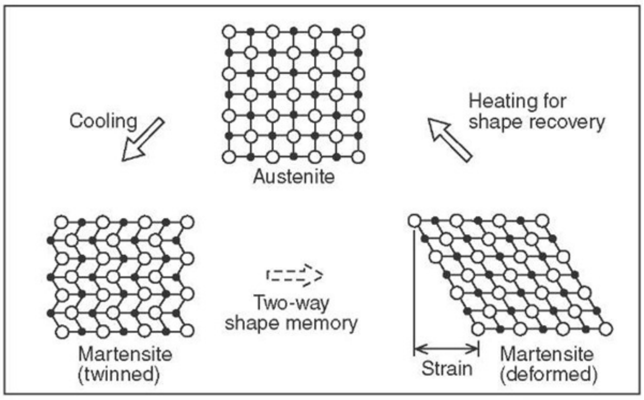

Figure 1. Principle of shape memory alloy (Chu et al., 2012).

The amount of titanium contained in it determines the transformation temperature of the wire to return to the programmed shape. This study uses wires with a conversion temperature of 45 degrees Celsius and a diameter of 1 mm, among Nitinol wires with a conversion temperature of 30, 45, and 60 degrees.

2. Methodology

This study examines the use of geometries created by shape memory alloys and origami folding techniques in heat activated facade designs. The methodology of the study consists of two basic steps: physical experiments and computational design. Physical experiments involve shaping and programming Nitinol wire, which is a kind of SMA, and creating foldable units based on flat and curved Origami folding techniques. Then, the study examines folding techniques to create kinetic systems and considers its transformation into kinetic structures through simulations and prototypes based on the two main variations, flat and curve folding techniques.

The second stage includes computational design, which transfers the physical behavior of Nitinol wire and foldable units into a digital environment by using Kangaroo add-ons operated by the Grasshopper (GH) algorithmic modeling environment. The second stage includes computational design, which transfers the physical behavior of Nitinol wire and foldable units into a digital environment by using Kangaroo add-ons that work with GH. The Kangaroo Engine simulates the folding behavior of paper and Nitinol wire with the help of an algorithmic flow in a digital environment. The folding geometries created in a physical environment transform parametrically in a digital environment. Then, two different folding geometries that can move parametrically are transformed into components for heat-active kinetic facades. Finally, using the Ladybug, Honeybee, Butterfly, and Kangaroo add-ons, the behavior of the heat-activated facade system has been simulated.

2.1. Physical Experiments

This study uses wires with a conversion temperature of 45 degrees Celsius and a diameter of 1mm. Criteria such as thermal reaction range and conversion rate are effective in the selection of the wire. Different types of nitinol programming methods have been utilized for different surface folds. The Nitinol wires, which were originally straight, have been fixed on wooden pieces with nails in the arc, zigzag, and flatform, which are appropriate shapes for transformation. The fixed wires are baked in a 500°C oven for approximately 5-7 minutes to be programmed into their given shape. The wire, which passes into the austenite phase at this temperature, has gained shape memory in the form in which it was fixed. Then, the wire has been manually shaped in order to realize the surface folding motion. In order for the folding movement to be carried out properly, the shaped wire is heated until it reaches the reaction temperature (40–45 °C). When it reaches the reaction temperature, the wire transforms into the shape it was first programmed into, thanks to its shape memory feature, and provides surface folding. Nitinol wires with a length of 10cm are programmed for each folding geometry and movement. Figure 2 illustrates the programming process for Nitinol.

After the programming experiments with Nitinol wires have been completed, the process of modeling foldable elements has started. Origami has faceted surfaces, fold lines, and joints. These parameters are important to understand the transformation of geometry. The fold lines and joints created on the surface define the form of the 3D geometry. Geometric transformations of patterns from 2D to 3D depend on the mathematical understanding behind folding types. The study handles flat fold and curve

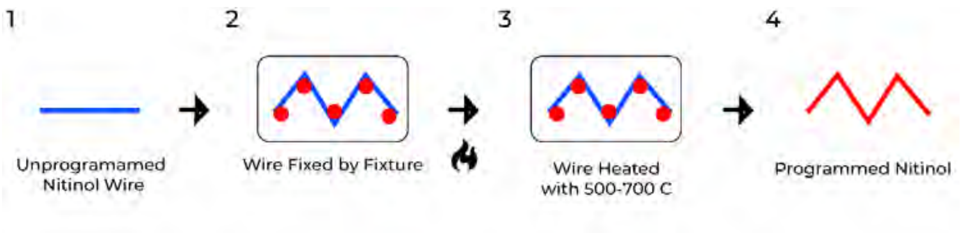

Figure 2. Nitinol programming process

fold patterns from the origami models Lang grouped in 2018 (Table 1) to produce physical prototypes (Lang, 2017).

Table 1. Lang's origami categorization (Lang, 2017).

Model	Description
Flat- Foldable Origami	All faces are flat and coplanar; creases have fold angle of 0 or 180 degree; paper has zero thickness
Polyhedral Origami	Facets are flat, creases are straight, but fold angles can vary continuously; paper has zero thickness
Curved Origami	Facets and creases can be curved; paper has zero thickness
Thick Origami	Paper thickness is explicitly included

In both folding techniques, fold lines are drawn on paper, and manual folding is performed. Then, the movement directions of the surfaces are determined, and an idea is obtained about how the Nitinol wire can be programmed and where it would be located. In order to generate geometry, the shapes of the wires before and after activation gain importance. For each folding operation, wires with a length of 10cm are programmed to exhibit appropriate folding behavior. It is then placed in its predetermined position, where it will transform the paper correctly (Figure 3).

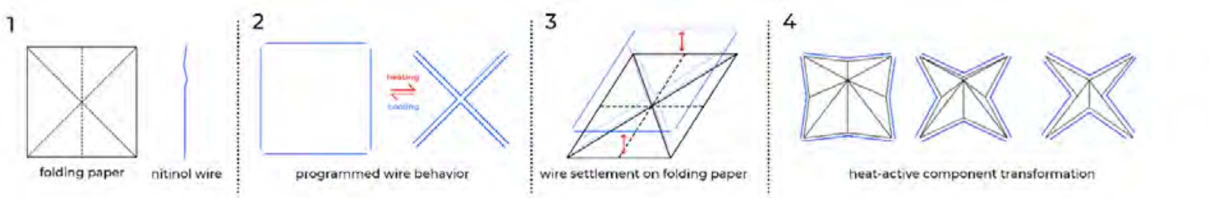

Figure 3. Physical Experiment Process

Figure 4 shows all alternative component models generated by Nitinol wire and paper in a physical environment. It also shows the fold lines of the surfaces created by the curved and flat folding techniques, the Nitinol wire geometry before and after folding, and the 3D physical model of the surface after transformation.

In the next step, patterns 3 and 4 in this table were used as moving parts for heat-activated facade systems and analyzed in a digital environment by the use of GH add-ons.

2.2. Computational Design Model

Since changes in ambient temperature trigger SMA, the relationship between ambient temperature and time is crucial. With the help of a systematic compilation of relevant weather data, ideal locations and suitable SMA activation temperatures for different scenarios can be identified. The aim is to design a structure for a self-sufficient operation, activated only during essential time periods such as temporary exposure to high direct solar radiation. For this purpose, physical models have been translated into computational design models. First of all, Pattern 3, as indicated in Table 1, which gives the maximum surface area change and surface opening before and after folding, has been chosen for the thermally active ventilation surface element. The 3D models

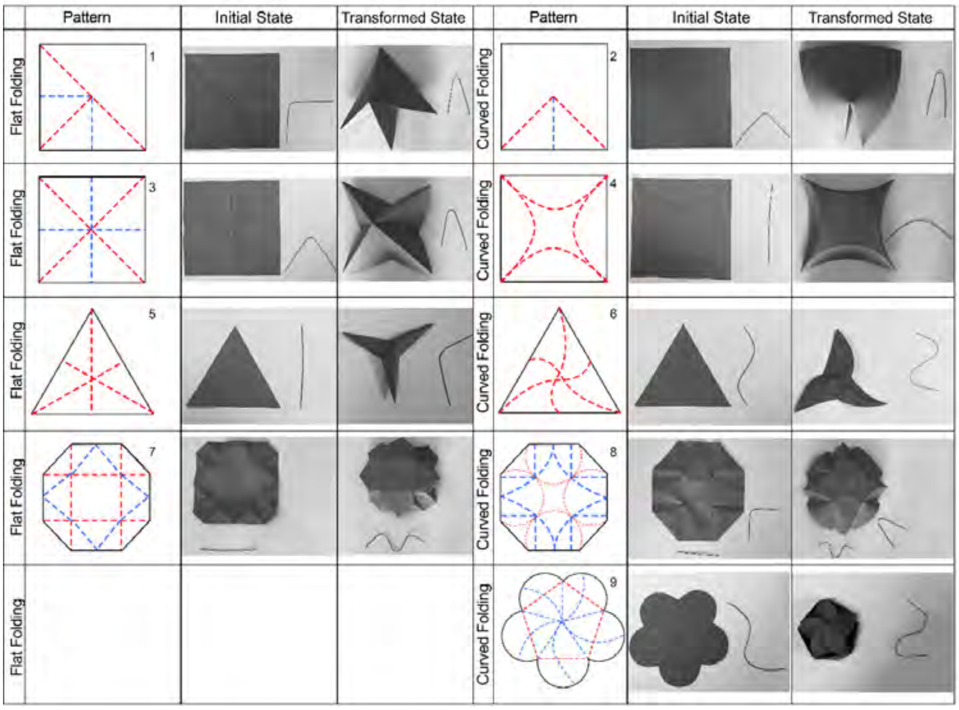

Figure 4. Folding patterns and model transformations with Nitinol wires

based on Pattern 3 have been modeled with Rhino and Grasshopper tools, and the Kangaroo plugin has been used for folding simulation of the model.

The first step for creating a foldable-facade element in a digital environment is to draw a base square plane. The plane has 10 x 10cm dimensions. Then, the fold creases are generated on this plane according to the folding behavior. As a second step, the points that determine the start and end of the folding are determined on the square plane, these points refer to the hinge component in the Kangaroo Engine. These hinge points also represent the locations of Nitinol wires in the physical environment. With the help of the parameter added to the hinge points, the folding angle of the surfaces is defined. The maximum and minimum rotation angles of the folding points have been parametrically defined in the range of 0–120 degrees based on physical experiments. Then, with the help of the forces applied to the hinge points, the surfaces are folded. The applied forces represent the bending forces that occur when the Nitinol wire is activated by the effect of temperature in the physical environment. After modeling a kinetic facade element, a curved facade layout is generated to observe the temperature difference on the surface. Afterwards, foldable and heat-activated composite panels are implemented on the designed facade. Figure 4 shows the modeling process of a heat-active facade element in the Grasshopper environment.

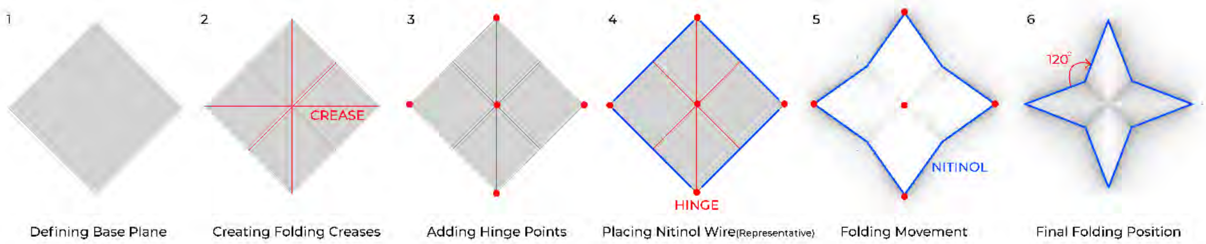

Figure 5. Digital Modeling Process of Heat-Active Panels

To test the behavior of a heat-activated façade system for ventilation, location data of a Mediterranean climate zone with suitable daily temperatures for the activation of Nitinol wires was used. Solar radiation analysis of the façade was made with Ladybug add-ons; facade elements were activated in areas where the surface temperature was sufficient and passive ventilation was provided. Then the Butterfly plugin was used to analyze the ventilation efficiency.

As a second scenario, a curved facade layout has been designed to better observe the temperature difference on the surface, similar to the first scenario. Pattern 4, as indicated in Table 1, which creates a curved surface when folded, has been chosen for the thermally active shading panel. Contrary to the previous facade system, the Nitinol elements on this façade are programmed to expand when heated and placed in the crease of the composite elements. However, similar component modeling processes to the previous one have been conducted. Solar Radiation Analysis and Grid View Illuminance Analysis have been performed on the surface by means of the Ladybug and Honeybee add-ons. The schematic workflow of computational model actions is shown in Figure 5.

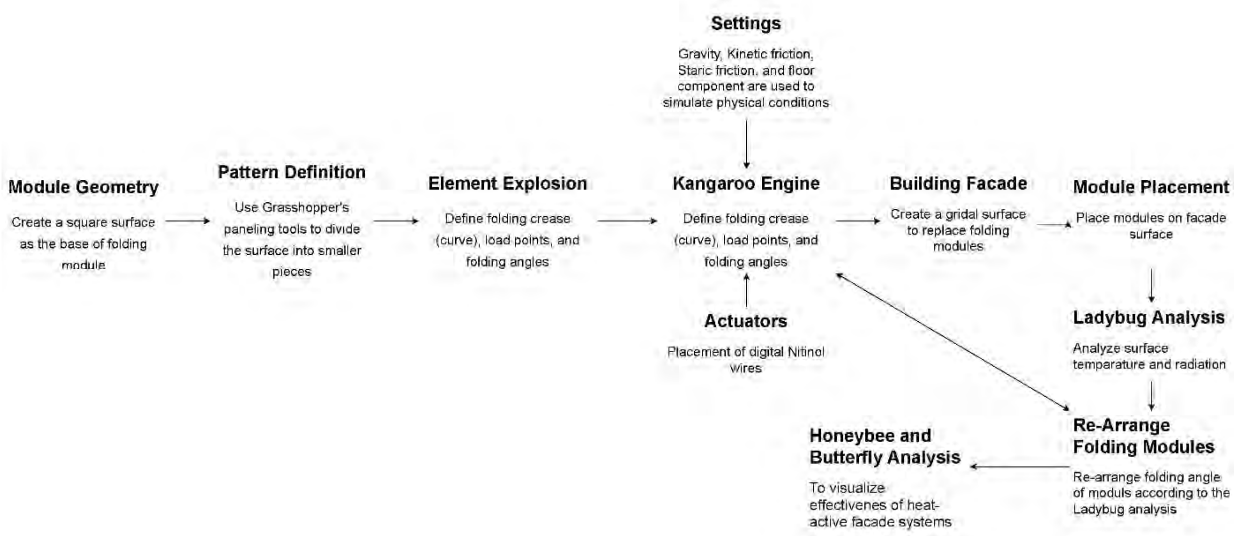

Figure 6. Schematic description of the proposed digital workflow

3. Results & Discussion

The facade generated by the use of the proposed methodology was analyzed with the help of the geological location data of the Mediterranean climate zone that represents appropriate daily temperatures for the activation of Nitinol wires. Figure 6 shows the hourly temperature data for the selected zone. When the temperature reached 40 °C, the facade panel responded in accordance with the Nitinol's behavior. While the red areas represent high temperatures, the blue areas represent low temperatures.

The resulting surface created by Pattern 3 models showed that facade elements exihibit kinetic behavior when the Nitinol wires reach the transformation temperature. In areas where the temperature reached a level that could activate Nitinol (above 5 kwh/m2 or 40 Celcius), the composite elements shrank and formed ventilation gaps on the surface. According to the climate data of the selected location, half of the Nitinol-based façade elements on the whole system were activated. Activated façade elements were compressed according to the nitinol behavior, creating gaps on the façade and providing air circulation between the interior and exterior. Ventilation analysis with the Butterfly plugin showed that the indoor air flow occurred at an average pressure of 30Pa, and the proposed facade system obtained effective ventilation. Figure 7 shows the results of the solar radiation analysis of the heat-activated facade surface and the ventilation analysis of the interior space ventilated to the heat-activated facade system.

The second model made by Pattern 4 showed that when the temperature reached the transformation temperature of Nitinol

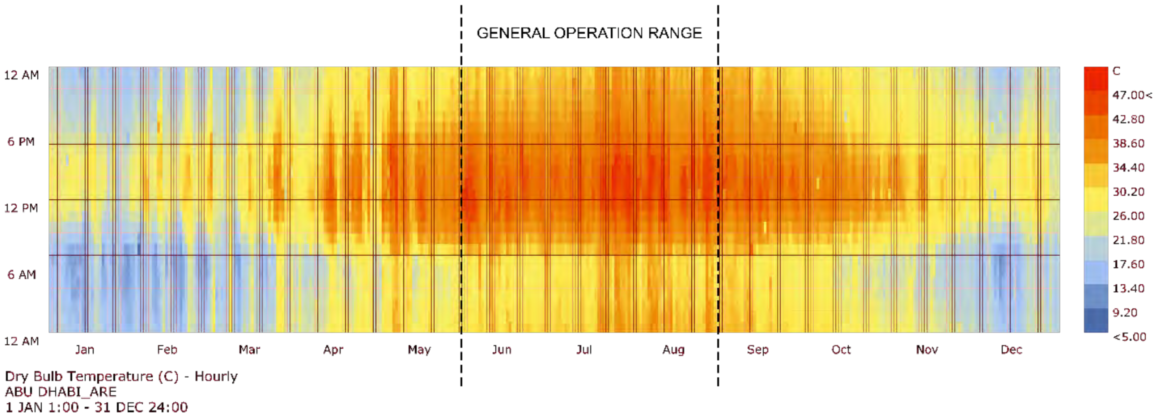

Figure 7. Hourly Dry Bulb Temperature of Selected Work Area

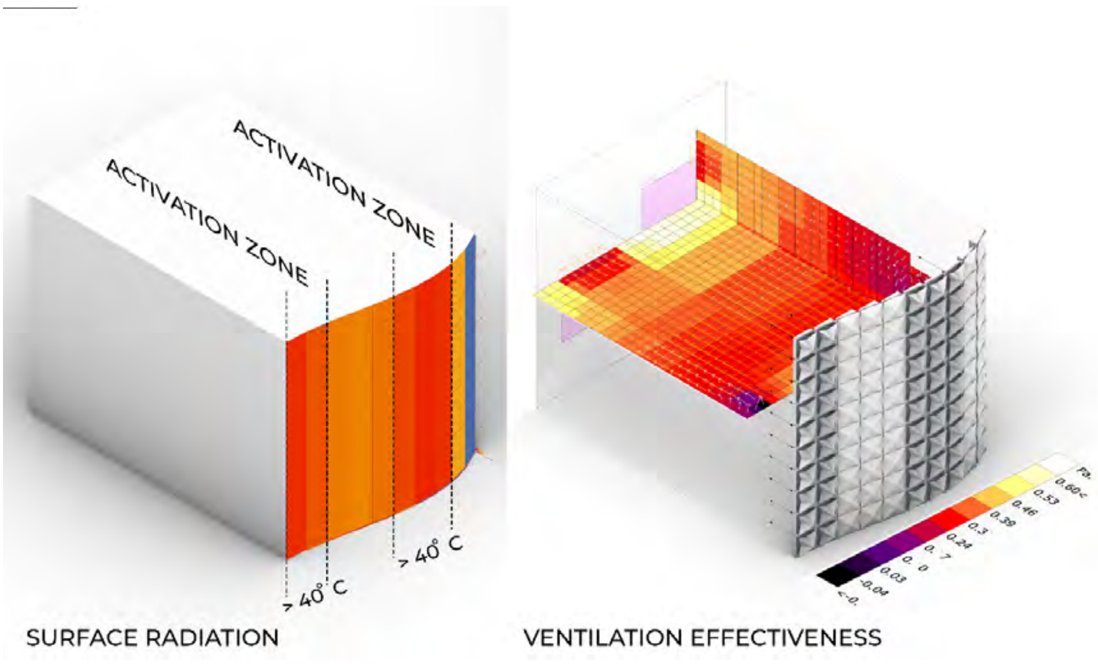

Figure 8. Results of base surface radiation analysis and ventilation analysis results of the heat-activated facade based interior

(above 5 kwh/m2 or 40 Celcius), the initially closed composite panels expanded with the expansion of Nitinol and shaded the area. According to the climate data for the selected location, forty percent of the nitinol-based facade elements on the whole system were activated. Nitinol didn't reach the activation temperature in the blue regions; therefore, no expansion movement was observed in the foldable composite panels. In the red regions, Nitinol reached the activation temperature, and the panels expanded with the action of Nitinol and provided maximum shading. According to the results of Daylight Illumination Analysis, the proposed heat- activated facade system gave positive results when compared to the passive facade system consisting of the same elements. According to the analysis carried out on the passive facade system, the indoor illumination level reached a maximum of 1000 lux and a minimum of 252 lux. In the heat sensitive facade system, when the indoor illumination value reached a maximum of 800 lux in areas close to the passive surface elements, it reached a minimum value of 112 lux in the regions where the elements provided active shading. Figure 8 shows the shading analysis of the heat sensitive active facade and passive facade systems in the interior space.

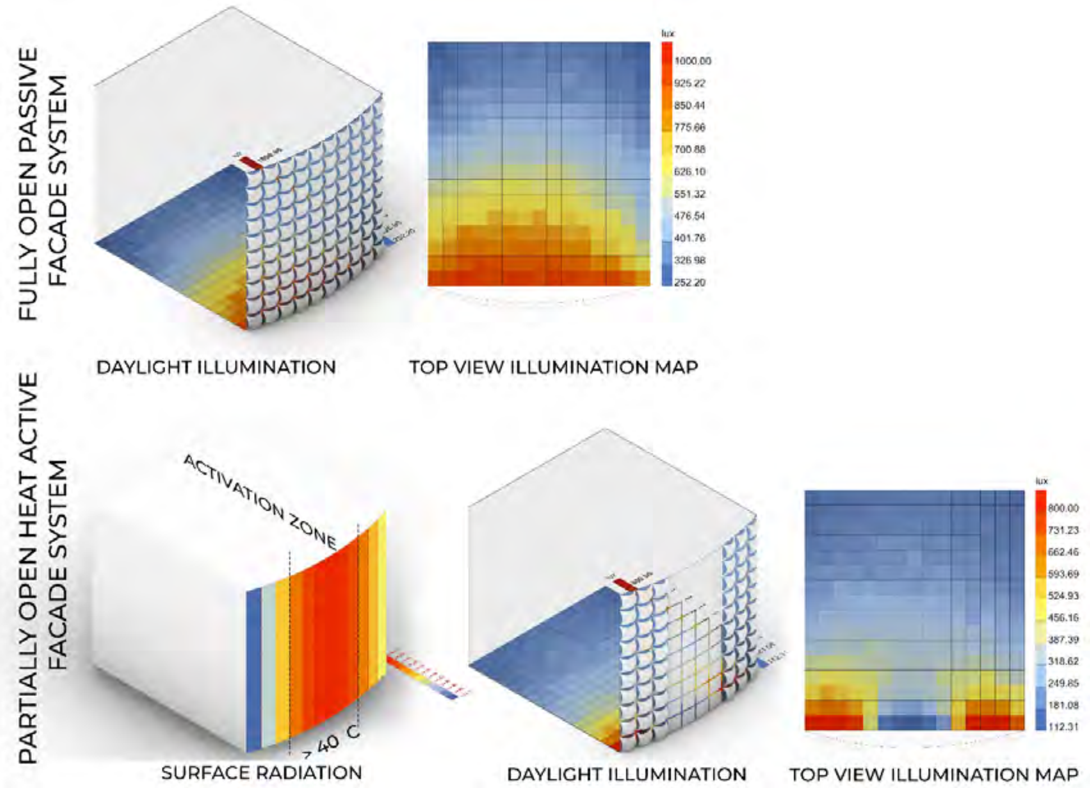

Figure 9. Passive facade based indoor shading analysis results and shading analysis results of heat-active facade based interior

The design proposal was undertaken experimentally. Even though the research began with basic analog models, a detailed interpretation of the material behavior and folding geometries has greatly aided the investigation of the methodology. After exploring the potential of Nitinol's behavior, different alternatives were tried in the process that was transferred to the digital environment. These alternatives were developed by considering the scale issue since the transformation movement of Nitinol wire would be affected according to the scale. In this direction, the process has progressed over composite facade elements, which have the same dimensions as the analog model (10 x 10 cm) and heat-active properties. Analyses were made on two different models to provide active ventilation and shading, and possible alternatives were illustrated (Figures 7 and 8).

The findings of this research showed that smart materials can be successfully incorporated into the design of kinetic building surfaces. Utilizing smart materials on the facade reduced building energy consumption, unlike other dynamic facade systems, which do not use smart materials but require mechanical and electronic components instead. In this study, dynamic systems using smart materials was developed as an alternative to other systems.

4. Conclusion and Future Work

The main purpose of this study is to understand the behavior of smart materials and contribute to the sustainability of the built environment. As mentioned previously, problems such as global warming and excessive resource use, sustainability and efficiency issues have started to gain more importance in all disciplines. This study focused on the use of SMA and folding techniques to explore the potential of using smart materials in architectural design. While physical experiments in the methodology involved shaping and programming Nitinol wire, the computational design process included transferring the physical behavior of this material and foldable units to the algorithmic modeling environment. The combined use of SMA actuators and responsive folding techniques will provide the potential to create shape-changing façade elements without the use of additional mechanical devices or energy.

The results of the study demonstrated that smart materials may be used for the design of intelligent systems. It also provides opportunities for further research and study in several domains. Various alternatives for facade systems can be developed by conducting experiments using different smart materials such as Al-Mn and Fe-Ni-Co-Al alloys or by creating various folding patterns and techniques such as polyhedral folding.

The scale of the material system used in both physical and digital models was relatively small compared to the components used on a building's facade. Thus, the proposed facade design should be considered as an experimental one by translating the behavior of the Nitinol from product to building scale. For further stages of the research, the scale issue should be further investigated and resolved by implementing the system at the building scale. It is expected that the use of smart materials in buildings will become widespread in the future with the help of similar research.

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RESEARCH ARTICLE

Finite Element Analysis of a Historic Masonry Building with Unique Architectural Features: A Case of KLP Building at İÜC Cerrahpaşa Campus

İhsan Kasım KARATAŞ[1], Barış YILDIZLAR[2], Barış SAYIN[2]

[1]Kastamonu University, Department of Construction, Kastamonu, Türkiye*
[2]Istanbul University-Cerrahpasa, Department of Civil Engineering, Istanbul, Türkiye

ABSTRACT
The walls and slabs of historic masonry buildings, as load-bearing members, tend to lose their strength and durability over time, which can lead to poor seismic performance. Rehabilitation and strengthening practices are performed to protect historic masonry structures and increase their lifespan. On the other hand, before a faithful restoration practice, assessing the seismic performance is important to perform strengthening work during restoration. With this purpose, this study presents a computational approach for seismic performance examination of a historic masonry building with unique architectural features constructed in the early 1930s. The study was composed of two stages; a historical background examination and a computational examination based on numerical analyses. The historical examination includes addressing all functional changes in the building from the construction date to the present. The numerical analyses involved preparing a three-dimensional finite element (FE) model based on the current state of the building and subjecting it to seismic loading. The analysis results revealed that the building is not seismically safe. The study is believed to provide a valuable contribution to the literature by presenting a numerical seismic assessment of the masonry building for consideration in the restoration process.

Keywords: Masonry buildings, Seismic performance analysis, Structural safety

1. Introduction

The primary goal of a repair or retrofitting intervention is to decrease potential sources of damage, reintegrate the building into society, or prevent further damage to the building. Since earthquake loads affect a building according to its weight and rigidity, increasing the rigidity and weight of a masonry building should be avoided during a repair or retrofitting practice (Çöğürcü, 2007). Currently, there is no distinct seismic code in Turkey that specifically addresses the structural assessment of historic buildings. Moreover, the evaluation of registered historic and cultural heritage structures and monuments is not encompassed in the Turkey Building Earthquake Code (TBEC, 2018). Therefore, historic buildings are subject to the same seismic code as other regular buildings due to the lack of a specific code for evaluating the seismic safety of historic structures. However, evaluating historic buildings requires a more complex approach than that for normal buildings, as various additional factors need to be considered. Most historic buildings were constructed using construction techniques and methods that were available during their time period. However, the current seismic code assesses the seismic performance of masonry buildings based on shear forces. On the other hand, performance assessment by considering only shear forces is an inadequate method for historic masonry buildings. To accurately evaluate the seismic performance of historic masonry buildings and propose effective retrofitting measures, it is necessary to consider building displacements under various loads, including dead loads, live loads, and earthquake loads, as well as the stresses on structural elements. New buildings constructed according to current seismic codes and standards are generally assumed to have a certain level of performance. However, the situation is different for historic buildings. Therefore, each historic structure should be examined for seismic performance using a proper and efficient method considering its architectural and historical significance.

Many studies on seismic performance assessment of masonry buildings were reported in the literature. Koçak (1999) presented some practices carried out for the protection and retrofitting of historic masonry buildings. A finite element model of the Little Hagia Sophia Mosque was developed and analyzed to determine dynamic features. The analytical and experimental results were

Corresponding Author: Barış SAYIN **E-mail:** barsayin@iuc.edu.tr

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compared. In another study, Sallio (2005) examined a masonry hospital building constructed in 1950 and found that the current state of the building has poor shear strength. A retrofitting proposal was presented, and the current and retrofitted states of the building were analyzed and compared. Taliercio and Binda (2006) presented a structural analysis of the Byzantine Basilica of San Vitale using a finite element model. Due to the complex geometry of the structure, linear elastic analysis was conducted based on the simplified rules. The results showed that the building could not carry its own weight. The findings obtained by the displacement measurements conducted with 6-month intervals matched with the performance analysis results. Özen (2006) modeled a masonry building in Hasankeyf, Turkey using the finite element method. The author performed linear and nonlinear analyses and compared the results. Both analyses showed that the damages were on the same section of the building. Therefore, they consider linear analysis is sufficient since nonlinear analysis takes more time. Betti and Vignoli (2008) examined static and dynamic -linear and nonlinear- analysis of historic masonry buildings and presented a seismic performance assessment of a basilica under earthquake loads. Strengthening suggestions were presented and compared based on the potential damage scenarios obtained by the analyses. Roca et al. (2010) discussed the practicality of limit analysis, simplified methods, finite element method, macro or micro modeling, and discrete element method for structural examinations. Ercan (2010) performed an operational modal analysis on two masonry buildings. The dynamic data obtained by experimental and numerical analyses were compared. The safety level of the buildings was assessed by static and dynamic analysis. Branco and Guerreiro (2011) compared the performances of various seismic strengthening techniques on an exemplary masonry building model. Some methods including reinforced concrete (RC) walls and viscous dampers were discussed. These methods were compared considering maximum displacements and stresses that occurred on the masonry walls under earthquake effects. Temur et al. (2013) examined earthquake risk analysis results of 57 different buildings. Due to some reasons including the number of examined buildings, limited time, as well as the complex geometry and irregular layout of the buildings, they employed the Rapid Assessment Method. Using this method, they determined the risk level of the buildings rapidly. Soveja et al. (2013) conducted a study addressing the complexity of the building and choosing the right modeling method for the analysis and strengthening of historic masonry buildings. They discussed the pros and cons of different modeling methods and evaluated their practicality. Yıldızlar and Akçay (2018) examined the current status of an educational building and assessed the safety level of the building using the Rapid Assessment Method before a strengthening practice. They also examined the effect of wrong interventions on the structural elements on the safety of the building.

Some modeling techniques are available for seismic analysis of historic masonry buildings. These are the simple wall model, crossbar model, equivalent frame model, and finite element modeling methods. Among these methods, finite element modeling is the most common method. The finite element modeling method involves the use of equations that describe the stress-displacement relationships of structural mechanisms. The program allows rapid assessment of complex analyses. There are various analysis methods available for evaluating the seismic performance of historic masonry buildings, including linear, non-linear, and time history analyses. Among these methods, linear analysis is the most common method. Linear analysis can employ the equivalent earthquake loading method. The design spectrum is determined according to the location of the examined building. The spectrum is then defined in the analysis program as the input for the earthquake load. The current seismic code stipulates that for each mode, the minimum ratio of total mass that effectively meets the base shear force to the total building mass should be 95% (TBEC 2018).

An extensive literature review indicated that numerous studies have been conducted on the seismic behavior assessment of historic masonry buildings. The reviewed studies addressed various aspects of assessing the seismic behavior of historic masonry buildings, including the determination of material properties of load-bearing members, comparison of linear and nonlinear analysis methods, kinematic analysis, time history analysis based on real earthquake records, and evaluations according to seismic code. The current study aims at assessing the seismic performance of a historic masonry building and evaluating the results according to the current seismic code. For this purpose, a finite element model of a building was prepared, and the seismic performance of the building was determined to inform restoration practices.

2. The examined building

The current building is a masonry style building with brick walls, consisting of two floors, has a closed area of 447 sqm (Figure 1). It is located within the campus of Istanbul University-Cerrahpaşa Faculty of Medicine in Fatih district, Cerrahpaşa neighborhood, Block 1138, and Plot 1. While still standing, the building has suffered the loss of many of its original and distinctive architectural element. The building has been utilized as the faculty of medicine for a considerable period. While the building was initially constructed to meet the faculty's classroom needs, it was used for various other purposes over time. The building was used as an amphitheater, pathological anatomy institute, x-ray unit building, and finally Consultation Liaison Psychiatry Department in the past. Recently, the building was closed down and abandoned.

After the *Istanbul Darülfünun* was closed and Istanbul University was established, the Faculty of Medicine in *Haydarpaşa* was moved to *Beyazıt* in 1933. Then, the central building of the Faculty of Medicine, administrative departments, institutes, and laboratories were moved to the War Office (*Harbiye nezareti*) building. The clinics of the Faculty of Medicine were distributed to

Figure 1. The current condition of the examined building

five different hospitals in Istanbul. On the other hand, Surgery, First Internal Medicine, and Eye clinics were moved to *Cerrahpaşa* Hospital (Figure 2).

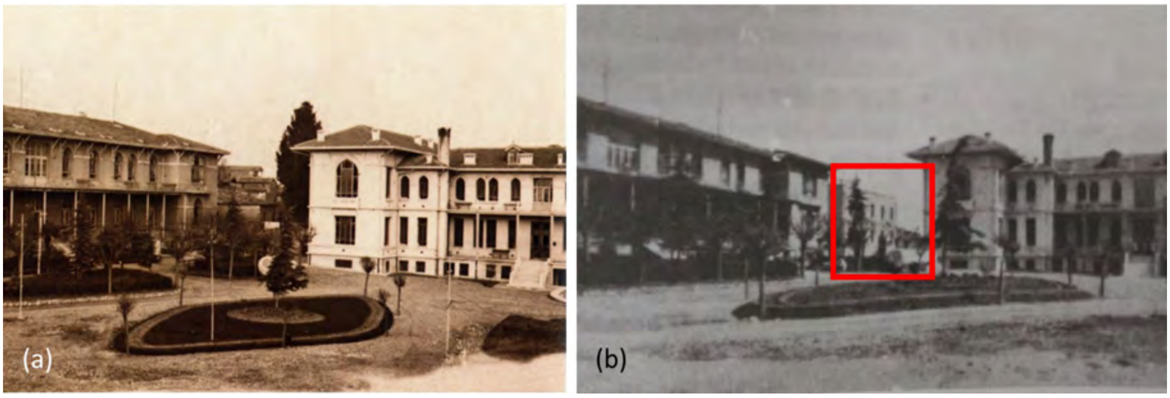

Figure 2. The examined building (a) Before construction, Internal Medicine and Surgery Clinic (Altıntaş, 2011), (b) After construction (Sarı et al., 2009)

Cerrahpaşa Hospital, which operated under the municipality in the past, has started to operate with the Istanbul University Faculty of Medicine since 1933. During the academic year of 1933-1934, the Faculty of Medicine had 1360 students, and around 180 students took courses specifically at *Cerrahpaşa* Hospital. In order to meet the increasing demand for educational activities and the insufficient capacity of the hospital, a classroom building was constructed between the Internal Medicine Clinic (Currently the Dean Building) and the Surgery Clinic (Currently the Psychiatry Clinic) as shown in Figure 3.

The construction of this building was completed in 1933 and was the first classroom building in *Cerrahpaşa*. Plus, it was the first building constructed by İstanbul University in *Cerrahpaşa*. After its construction, the building was referred to as the *Cerrahpaşa* Classroom building, but it was later renamed the *Neşet Ömer* Amphitheater to commemorate Rector Neşet Ömer İrdelp's death in 1948 (Altıntaş, 2011). The current status of the amphitheater is shown in Figure 4.

The building was constructed in masonry construction style using bricks. The load-bearing walls were built using clay bricks and mortar composed of a hydraulic lime-aggregate mixture (Figure 5). Slabs - which is an important component of the load-bearing system- were built as RC slabs. The utilization of RC slabs instead of the more common jack arch slabs, frequently employed in historic masonry buildings, suggests that the construction of this building differs from other similar structures of the same period.

2.1. Original plan features

A restitution report was prepared to identify the original architectural features of the building (Proger S.p.A & ZH Co. 2013). Based on the findings of the restitution report, the building consists of a ground floor, a standard first floor, and a standard second floor, all constructed using masonry brick walls in a masonry style (Figure 6). Also, the building has a hip roof. In later times,

Figure 3. The original building in 1930-1933 (view from the southwest)

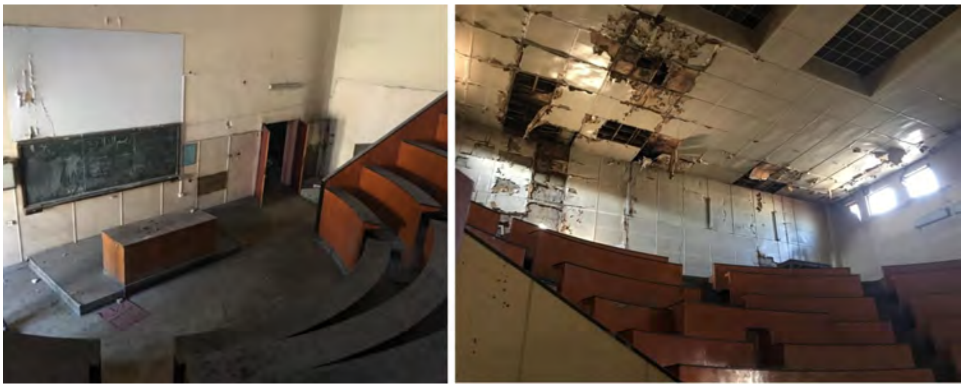

Figure 4. The current status of the amphitheater

unqualified interventions were made to the roof. Marseille tiles were used in the roof covering. Gable walls were used around the roof, next to the slope of the roof. The top of the amphitheater classroom was illuminated by sunlight.

The main entrance of the building is located on the south façade. "The masonry brick facades of the building were covered with a layer of cement plaster, followed by an RC-based material and paint.

Another RC building was constructed in later times next to the south façade of the examined building.Shared spaces were created between the examined building and the consultation-liaison psychiatry building. The main entrance is accessed through an iron double-door that appears to have been improperly installed during a later period of the building's history. Some improper connections were made to link the building with surrounding buildings. An RC tunnel (Figure 7) was added to link the building to an adjacent structure, with a door opening to the neighboring building (the Dean building). While the ground floor of the building remained within its original borders, expansions were made to some areas on the first and second floors. On one of the façades has two separate entrances, with the first providing direct access to the largest section of the building, the amphitheater, through a double-winged iron door added at a later time. The second entrance, which is located on the ground floor, was created by converting an original window opening into a doorway.

During the restoration process, the wall plasters were removed to partially uncover the connections between the structural elements, revealing the presence of horizontal and vertical RC peripheral ties in some of the walls. It should be noted that not all walls had horizontal and vertical RC peripheral ties. As shown in Figure 8, in some sections wall-slab joints were through horizontal RC peripheral ties, while in other sections, RC slabs were directly connected to the masonry walls.

Figure 5.(a, b) Masonry walls, (c) RC Slab

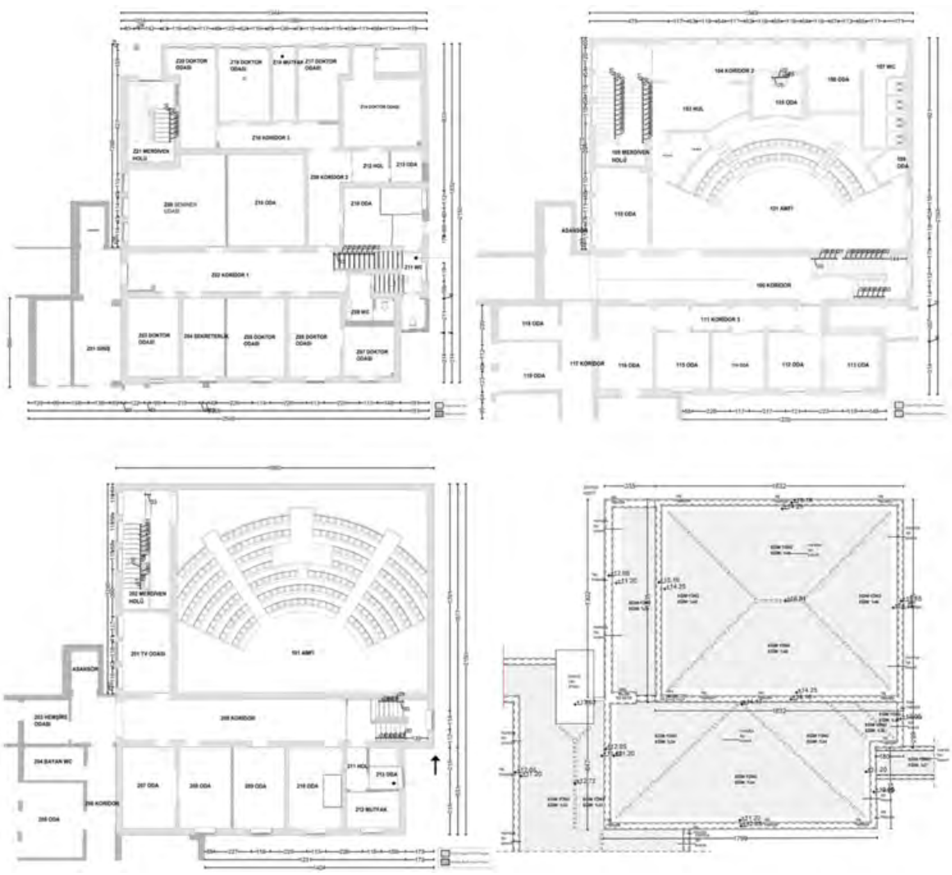

Figure 6. Plan views of the ground, 1st, and 2nd floors

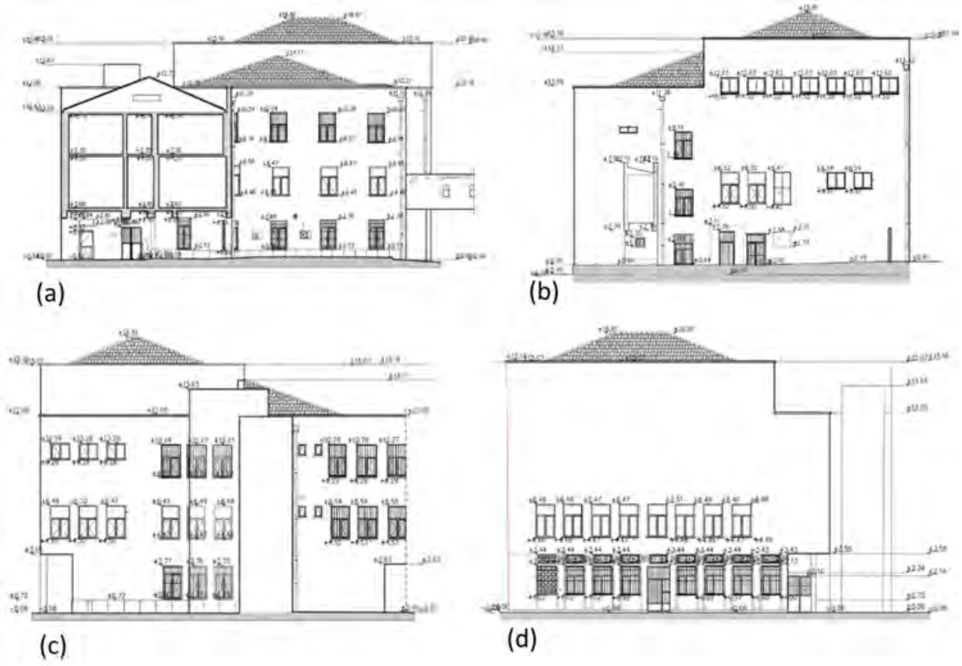

Figure 7. Façade views of the examined building. (a) South, (b) East, (c) West, (d) North

Figure 8. Connection details between the structural elements

2.2. Interventions made to the Load Bearing System

The examined building has undergone numerous interventions throughout its history, resulting in the loss of several unique components.

The interventions carried out on the building aimed to adapt it for a change of use or to repair and strengthen it following damages caused by seismic events. Examples of revisions to the building's architectural plan due to changes in use include the cutting of window and door openings in the load-bearing walls (Figure 9). After scraping the wall plasters, some openings were discovered which had negative effect on the load-bearing capacity of the walls. To fill these openings, new perforated bricks were used. On the other hand, steel columns and beams shown in Figure 10 are examples of the strengthening interventions performed in the past.

Figure 9. An opening cut in the masonry wall (later closed)

Figure 10. Steel columns and beams added to the building

These steel columns and beams were discovered after removing suspended ceilings and demolishing later-added walls.The most significant interventions made to the building involved the addition of connections on both side facades, which were designed to provide access to adjacent buildings. The original plan of the building includes only one access to the Dean Building from the 1st floor. However, as seen in Figure 11, additional connections were later made to the ground and 2nd floors to connect with the Dean Building.

The original plan did not include a connection to the Psychiatry Clinic from the south façade. However, an RC structure was constructed in 1951 to connection the buildings as seen in Figure 12. This building was later used as the Department of Pediatric Mental Health and Diseases.

Figure 11. Current connection of the building to the Dean Building

Figure 12. Connection of the building to the Psychiatry Clinic

3. Numerical Analysis

A numerical model was developed to simulate the structural behavior of the examined building, considering its plan features. The model included one ground and two normal stories and was subjected to dead and live loads representative of the building's intended function. The building model underwent a seismic analysis, and its performance was evaluated based on the criteria outlined in TBEC 2018.

3.1. Modeling

The 3D finite element model of the examined building was created on the Midas Gen 2019 program. Masonry walls were modeled using three or four-node shell elements. To accurately represent the actual condition of the building, structural illegalities and geometric defects obtained by on-site observations were incorporated into the model. The floor plans were idealized on CAD software to create a 3D-rod model, which was then defined in the Midas Gen software. For seismic evaluation, the areas with maximum stress were chosen as critical sections, as seen in Figure 13. These sections were located below the window elevations on all floors. A 3D view of the model is shown in Figure 14.

In the numerical model, critical sections were represented as wall members with varying thickness, while all other members were modeled as plate elements. These sections were identified and coded based on their corresponding wall numbers, and the analyses were evaluated considering these sections. Slabs were modeled as plate elements, while wall-slab connections were modeled as fixed supports.

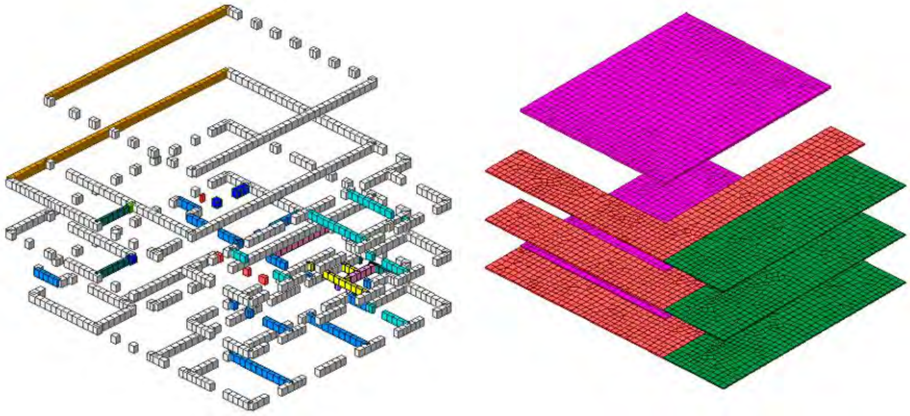

Figure 13. Critical wall sections and story slabs

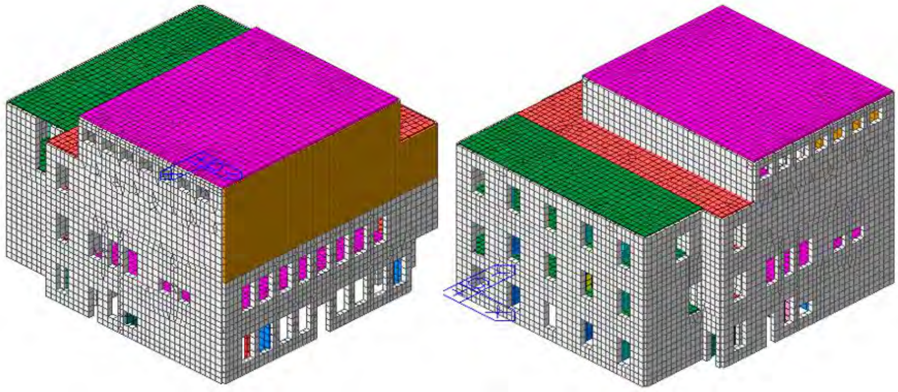

Figure 14. The finite element model

Dead and live loads were incorporated into the finite element model based on the specifications provided in the TS498 standards. After defining the structural behavior according to TBEC2018 in the program, earthquake loads were calculated using the earthquake load coefficient. The coefficient was calculated based on the mass participation ratio obtained from the modal analysis. These loads were then applied to the building in the numerical model. The parameters used in the static analyses are given in Table 1.

Table 1. Analysis parameters

Parameter	Value
Local soil class	ZD
Ground Motion Level	DD2
Earthquake Map Spectral Acceleration (g)	S_s = 1.005, S_1 = 0.277
Earthquake load reduction factor (Ra)	1
Building Importance factor (I)	1
Live Load Participation factor (n)	0.6
Seismic Design Class (DTS)	1a
Building Height Class (BYS)	6

3.2. Material Parameters

Material tests were carried out on the walls and reinforced concrete floors for the strengthening and repair works of the examined building. The report of the experiments was obtained from the Construction and Technical Department of Istanbul University.

However, these test reports do not include shear and compression tests for the walls. Only the physical characteristics of the bricks and binder materials were examined. For the reinforced concrete slab, only two cores were taken from the second floor, and a compressive strength test was carried out on them. The test results are shown in Tables 2 and 3.

Table 2. Test results for wall components (Özgünler, 2019)

Sample	Specific weight (kg/lt)	Water absorption % (by weight)	Binding/Aggregate ratio
Sample 1: Brick	2.53	26.8	“-“
Sample 2: Joint mortar	2.55	17.9	1 volume binder to 7.4 volumes aggregate
Sample 3. External plaster	2.57	11.1	1 volume binder to 5.2 volumes aggregate
Sample 4-1. Internal plaster	2.57	17.3	1 volume binder to 6.58 volumes aggregate
Sample 4-2. İnternal plaster (Dark colored)	2.48	48.2	1 volume binder to 5.28 volumes aggregate

Table 3. Cylindrical compressive strength test results for reinforced concrete slabs (Özgünler, 2019)

Core	Dimensions (diameter and length in mm)	Compressive strength (N/mm^2)
Core 1 (No 5)	93.2x94.0	22.1
Core 2 (No 6)	93.2x90.5	19.8
	Average	20.95

The modulus of elasticity of concrete used in the seismic analysis was calculated according to TS500 in line with the cylindrical compressive strength test. In seismic analysis, 85% of the average characteristic compressive strength of cubic samples was used. The modulus of elasticity was then calculated using Equation 1. Accordingly, the characteristic compressive strength of the concrete was calculated as 17.81 MPa and the modulus of elasticity was calculated as 27715 MPa. These values were considered in the seismic analysis.

$$E_{cj} = 3250\sqrt{f_{ckj}} + 1400\ (MPa) \quad (1)$$

The specific weight used in the analysis was determined by calculating the average of the specific weights of the brick, mortar, and plaster material as seen in Table 2. Due to the unavailability of compression and shear test results, these parameters were obtained from the test report of a similar historical building with similar characteristics to the examined building. This reference building, the Istanbul University Faculty of Political Sciences Building, is used since it contains structural components representing different construction techniques. The test results of this building are summarized in Table 4. The average unit and characteristic compressive strengths were obtained from the brick and wall compressive strengths given in this table.

Table 4. Test results of the Istanbul University Faculty of Political Sciences (Akro Co, 2012)

Story	Test No	Compressive Strength of the Brick (Mpa)	Compressive Strength of the Wall (Mpa)
1	T1	4.803	2.402
1	T2	6.015	3.008
2	T3	5.579	2.789
2	T4	6.817	3.409
3	T5	5.455	2.727
	Average	5.7338	2.867

3.3. Soil and Earthquake Parameters

According to the V_{30} average shear-wave velocity mapping for the location of the examined building, the local soil class was determined as “ZD”. TBEC 2018 envisages four different ground motion levels. In the seismic analyses, ground motion level-2 (DD-2) with a 10% probability of exceedance in 50 years (a return time of 475 years) was considered. Elastic acceleration spectrum characteristics were selected based on the soil class. The spectrum curve was drawn according to the local soil class given in TBEC

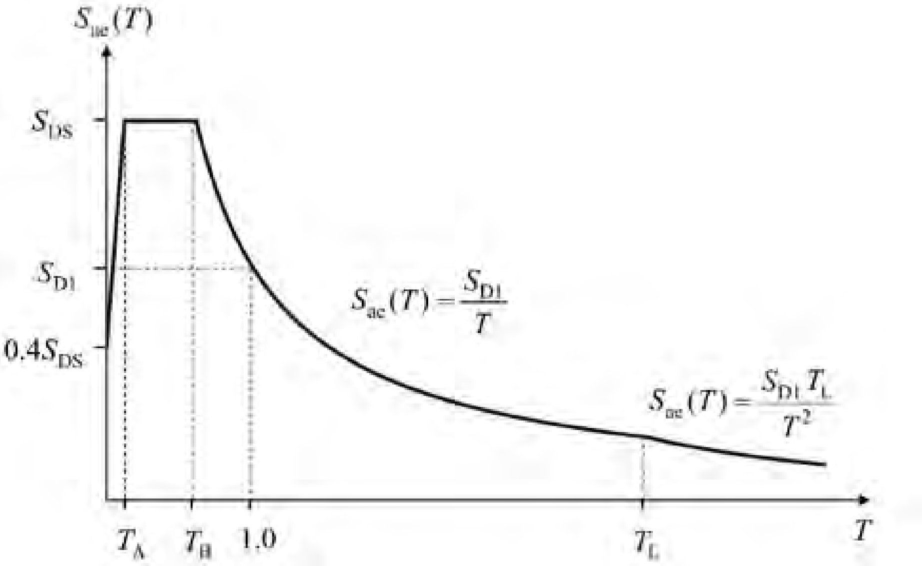

Figure 15. Spectral accelerations and lateral elastic acceleration spectrum

2018. Earthquake map spectral accelerations (S_s and S_1) were determined using the Turkey Earthquake Hazard Maps Interactive Web Application (AFAD, 2019).

Based on the location of the building on this map, spectral accelerations were determined as S_s = 1.005g and SS_1 = 0.277g for an earthquake with a return time of 475 years. Load soil factors were calculated as (F_s and F_1) F_s = 1.098 and F_1 = 2.046 according to the spectral accelerations and local soil class of "ZD".

Spectral accelerations were calculated by multiplying Earthquake map spectral accelerations with local soil class factor using Eq. 2.

$$S_{DS} = S_S x F_S = 1.0051.098 = 1.103$$
$$S_{D1} = S_1 x F_1 = 0.2772.046 = 0.567 \quad (2)$$

Accordingly, lateral elastic spectral accelerations [S_{ae}(T)] and lateral acceleration corner periods (T$_A$and T$_B$), were calculated using Eq. 2, the criteria given in TBEC 2018, and the elastic acceleration spectrum was created (Figure 15).

3.4. Structural Parameters

According to TBEC 2018, Ra was taken as 1 for the Mod Combination Method, which is the linear seismic analysis method used for the current building. The building importance factor (I) was considered in the seismic analysis of the examined building, and it was assigned a value of 1 according to TBEC 2018. The Live Load Participation Factor (n) was determined as 0.60 since the building was used for educational purposes.

Seismic Design Class (SDC) was determined as 1 based on the criteria outlined in TBEC 2018. Short period design spectral acceleration (S$_{DS}$) was calculated according to the Building Usage Class. Furthermore, according to the criteria given in TBEC 2018, Building Height Class (BHC) was taken as 6.

3.5. Performance Analysis Assumptions

The building information factor was chosen as limited information and accordingly, the building information factor was taken as 0.75. To assess the seismic performance, Mode Combination Method, a linear static calculation method was selected. The building should meet "Controlled Damage" performance criteria for a DD-2 ground motion with a 10% probability of exceedance in 50 years (return time of 475 years). For masonry walls; i) a building is classified as having "Limited Damage Performance" if the shear capacity of all walls meet shear demand caused by earthquake; ii) a building is classified as having "Controlled Damage Performance" if the ratio of walls in a given story that fail in shear is below 40%; iii) a building is classified as being in a "Collapse" state if the ratio of walls in a given story that fail in shear is above 40%.

4. Results and Discussion

For evaluation of the analysis results, SINAN software (Okumus, 2019) was used. The modes, natural vibration frequency, and mass participation ratios of the building were determined and are shown in Figure 16.

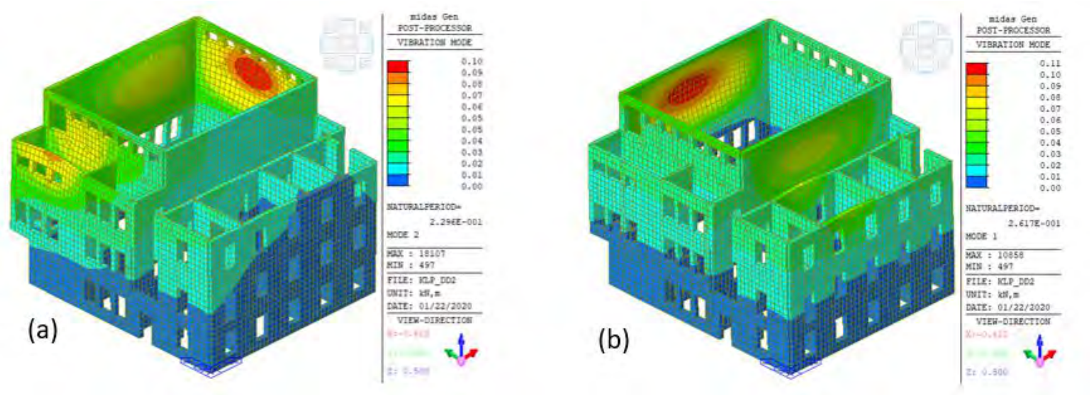

Figure 16.(a) Mode 1, T = 0.26 s, movement in the y direction, (b) Mode 2, T = 0.23 s, movement in the x direction

Modal analysis of the building under earthquake effects was performed. The number of vibrational modes required for the modal analysis was determined based on the criterion that the sum of total effective masses for each mode in the x and y directions should account for at least 95% of the building's total mass. Accordingly, the criterion was met for the first 35 modes in both x and y directions. The first dominant mode of the building was the 1st mode and the mass participation ratio and the period for lateral movement in the y direction were found to be 50.52% and 0.26 s, respectively. The second dominant mode of the building was the 2nd mode and the mass participation ratio and the period for lateral movement in the x direction were found to be 35.4% and 0.23 s, respectively.

The maximum displacement of the building was found to be 16.9 mm under vertical loads. Displacements observed under fixed and reduced live loads are shown in Figure 17. The walls of the amphitheater and the north façade walls exhibited the highest displacement values.

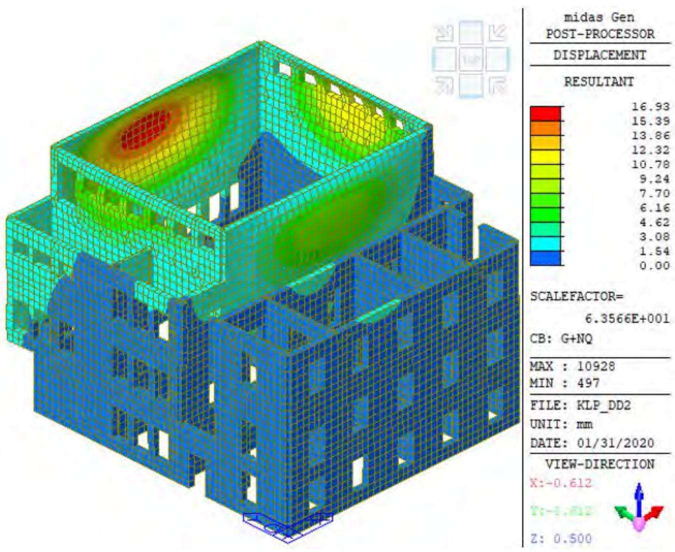

Figure 17. Displacements observed under dead and live loads (G+nQ) (G:Dead load, Q: Live load, n: Live load reduction factor)

The displacements observed under earthquake combined load effects in the positive x direction are shown in Figure 18a.

Under this loading, the wall of the amphitheater on the north façade of the building exhibited the maximum displacement of 93.1 mm. The displacement distribution in the x direction was observed to increase from the lower part of the 1st floor to the top of the building. The displacements observed under combined load effects in the negative x direction are given in Figure 18b.

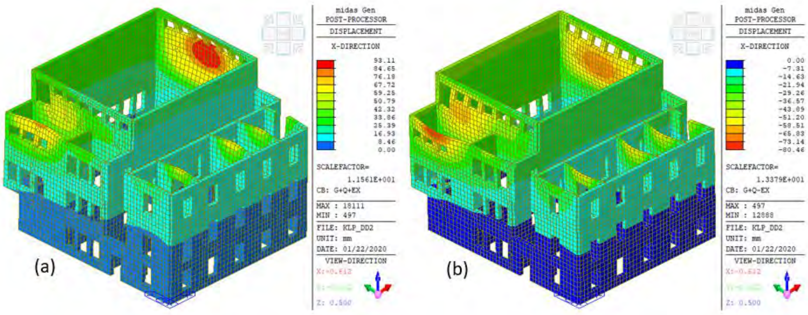

Figure 18. Lateral displacements under earthquake effects in the x direction (a) G+Q+Exp, (b) (G+Q-Exn) (G:dead load, Q: Live load, Exp: Earthquake load in the positive x direction)

Under this loading, a maximum displacement of 80.5 mm was observed on the 2nd floor, exterior wall of stair hall no 202 on the west façade. Additionally, displacement values up to 73 mm were observed on the west façade. The amphitheater walls on the east façade also experienced significant displacements.The displacements observed under earthquake combined load effects in the positive y direction is shown in Figure 19a, a maximum displacement of 147.2 mm was observed in the amphitheater wall on the north façade of the building. Since the first dominant mode of the building was in this direction, the maximum displacement was observed in this direction. The displacements observed under earthquake combined load effects in the negative y direction are shown in Figure 19b. Under this loading, a maximum displacement of 110.9 mm was observed in the amphitheater wall on the north façade of the building. Since the first dominant mode of the building was in this direction, significant displacements were observed in this direction.

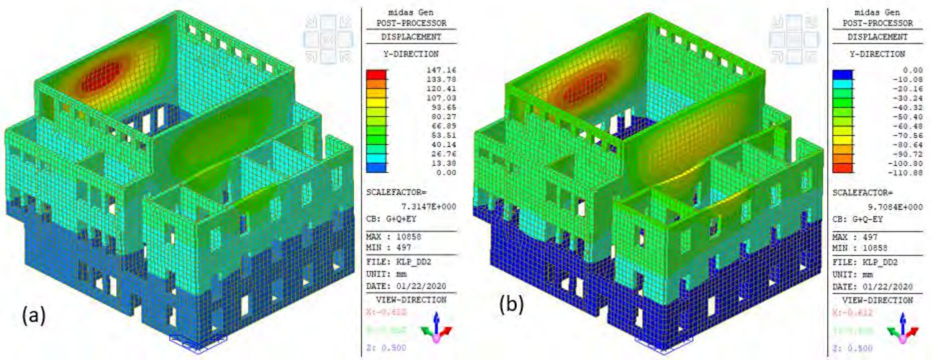

Figure 19. Lateral displacements under earthquake effects in the y direction (a) G+Q+Eyp, (b) (G+Q-Eyn) (Eyp: Earthquake load in the positive y direction, Eyn: Earthquake load in the negative y direction)

Figure 20a displays the stresses induced by the earthquake combined load effects in the positive x direction. These stresses represent axial stresses acting in the x direction, which is perpendicular to the y-z plane. An examination of the observed stresses showed that the maximum axial stress of 4929 kN/m^2 was observed on the exterior wall-wall connections of the north façade. Compression effects on the west and east façade walls resulted in tensile stresses, mostly observed on the north and south façade walls. The stresses observed under earthquake combined load effects in the positive y direction are shown in Figure 20b, representing axial stresses in the y direction perpendicular to the x-z plan. An examination of the observed stresses revealed that the east façade walls, around the window openings of the amphitheater, exhibited the maximum stress of 5690 kN/m^2. The compressive effects on the north and south façade walls resulted in tensile stresses mainly on the west and east façade walls.

Figure 21a shows the axial stresses perpendicular to the x-y plane observed under earthquake combined load effects. The highest compressive and tensile stresses were observed along this axis. An examination of the observed stresses showed that the walls of the amphitheater had the highest stresses, with a maximum stress of 15000 kN/m^2 observed on the west façade walls between the upper window openings.Furthermore, tensile stresses observed under earthquake combined load effects in the positive x direction are shown in Figure 21b. These stresses represent tensile stresses on the y-z plane. An examination of the stresses showed that a maximum stress of 4266 kN/m^2 was observed on the east façade, on the upper window lintels of the amphitheater. These tensile stresses, perpendicular to the earthquake axis were relatively high.

Stresses observed under earthquake combined load effects in the positive x direction are shown in Figure 22a. These stresses

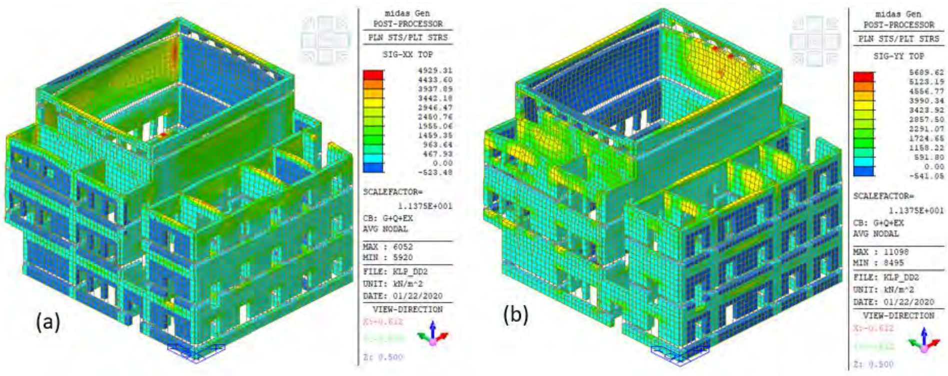

Figure 20. Stresses occurred under G+Q+Exp loading

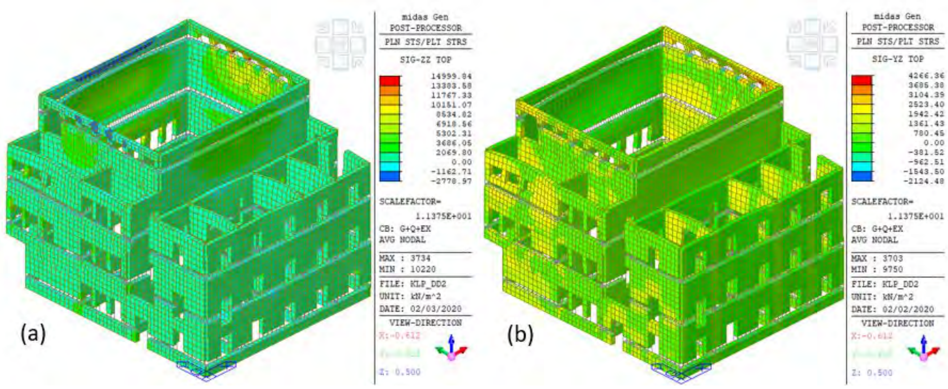

Figure 21. Stresses occurred under (a) G+Q+Exp loading, (b) G+Q+Exp loading

represent shear stresses on the x-z plane. Based on the obtained results, the highest stress value of 2958 kN/m^2 was observed on the exterior walls of the north façade at the 2nd floor. The shear stresses on the window and door lintels of the walls in the x-axis reached a maximum of 1500 kN/m^2. Stresses observed under earthquake combined load effects in the positive y direction are shown in Figure 22b. Upon examining the stresses, it was found that the joints of the exterior walls on the north façade experienced the highest stress, with a maximum value of 5100 kN/m^2. The walls on the y-axis generally experienced compressive stresses, while those on the x-axis experienced tensile stresses.

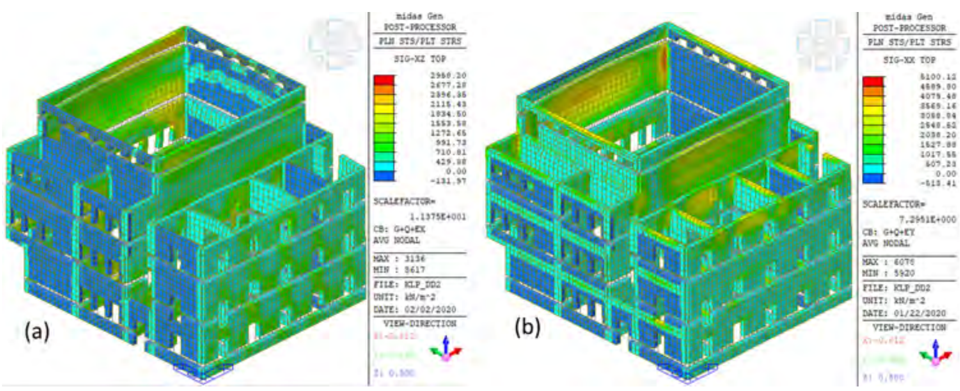

Figure 22. Stresses occurred under (a) G+Q+Exp loading, (b) G+Q+Eyp loading

Figure 23a shows axial stresses observed under earthquake combined load effects in the positive x direction. The analysis revealed that the highest stress was 6608 kN/m^2, which occurred on the east façade between the window openings of the 2nd floor exterior walls. Figure 23b shows axial stresses in the positive y direction. An examination of the stresses showed that a maximum stress of 11318 kN/m^2 was observed on the north façade, on the amphitheater wall and between the window openings and the door lintels of the 2nd floor.

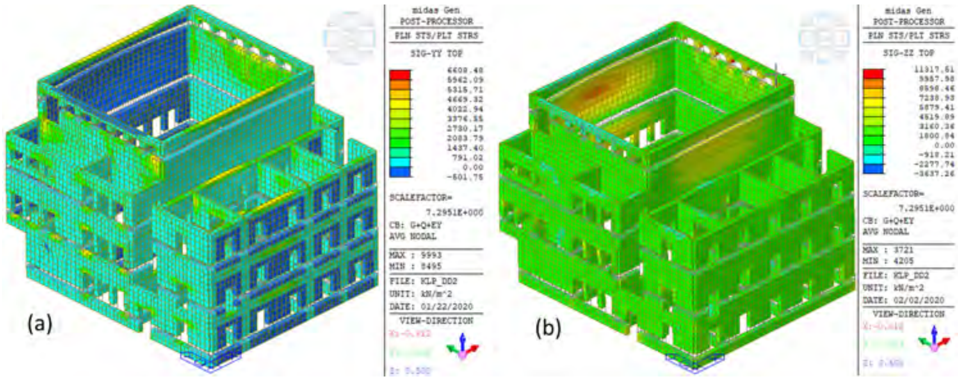

Figure 23. Stresses occurred under (a) G+Q+Exp loading, (b) G+Q+Eyp loading

Shear stresses observed under earthquake combined load effects in the positive x direction are shown in Figure 24a. The obtained results revealed that the upper window lintels of the amphitheater walls on both the east and north façades experienced a maximum stress of a maximum stress of 3671 kN/m^2. Figure 24b shows shear stresses observed in the positive y direction. The obtained stresses revealed that the maximum stress of 3345 kN/m^2 was observed on the upper parts of the exterior walls on the northeast façade. Moreover, shear stresses of 1600 kN/m2 were observed on the window and door lintels of the x-axis walls.

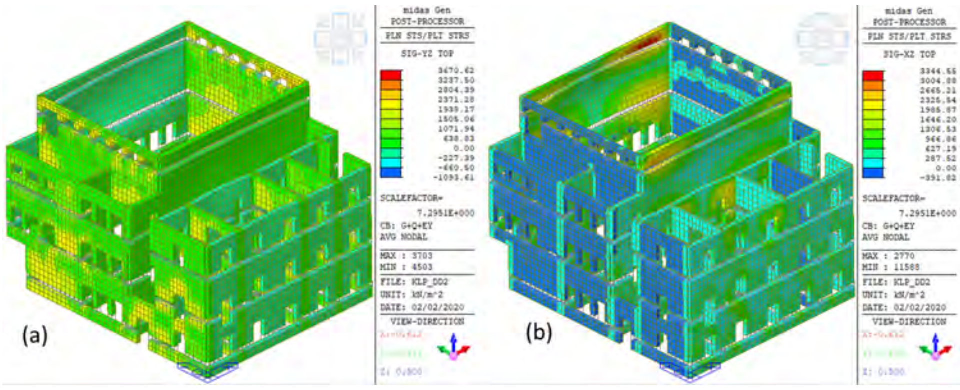

Figure 24. Stresses occurred under (a) G+Q+Exp loading, (b) G+Q+Eyp loading

5. Conclusions and Remarks

In this study, a three-dimension finite element structural model was created and analyzed to assess the seismic safety of a historic masonry building. The results obtained by the seismic analyses indicated that the building does not withstand the shear forces that occurred under both earthquake directions. Therefore, the building was determined to have a poor seismic performance and was at risk of collapse. On the other hand, the building's seismic performance under vertical loads was found to be within acceptable limits. The examination of the building displacements under earthquake effects showed that walls displaced up to 150 mm. Particularly, the highest displacements were observed on the amphitheater walls on the 1st and 2nd floors. Furthermore, the examination of the stresses under earthquake effects showed that stresses reached up to 15000 kN/mm^2. The stresses were observed on the load-bearing members under compressive and tensile conditions due to earthquake loading.

Since there is no regulation specific to historical buildings, seismic analysis and evaluation of such buildings are made according to the principles determined for masonry structures in the Turkish Building Earthquake Regulation.

Performance analysis results were evaluated as follows in accordance with the regulation:

- On the ground floor, the ratio of masonry walls that do not meet the required shear force capacity in the x-direction (100%)

and y-direction (100%) is above the limit value of 40%. As a result, this floor is unable to achieve the desired 'Controlled Damage' performance level and is classified as being in a 'Collapse' state.
- On the ground floor, the ratio of masonry walls that do not meet the required shear force capacity in the x-direction (99.98%) and y-direction (100%) is above the limit value of 40%. As a result, this floor is unable to achieve the desired 'Controlled Damage' performance level and is classified as being in a 'Collapse' state.
- • On the second floor, the ratio of masonry walls that do not meet the required shear force capacity in the x-direction (%99.98) and y-direction (100%) is above the limit value of 40%. As a result, this floor is unable to achieve the desired 'Controlled Damage' performance level and is classified as being in a 'Collapse' state.

Considering the seismic analysis results and the current seismic code requirements, the structure was found to be unable to resist the shear forces generated by earthquakes in both the lateral and vertical directions. Additionally, the building's ability to withstand vertical loads was found to be adequate, but it has poor resistance to horizontal loads.

In conclusion, the building was not seismically safe due to its masonry load-bearing system, structural geometry, material properties, construction conditions, as well as shear capacity. Considering the shear forces, displacements, and stresses observed on the building under earthquake loading, it was recommended that the building should be strengthened as soon as possible before facing a major earthquake.

Current seismic code considers only the shear forces when assessing the seismic performance of masonry buildings. Therefore, many historic masonry structures would be deemed to have poor seismic performance under the current code. However, evaluating historic masonry buildings based solely on their shear capacity and treating them like regular buildings in terms of seismic requirements is not appropriate. To obtain more functional and accurate results while evaluating historic masonry buildings, it is recommended to prepare a separate seismic code specifically for their analysis and interventions.

Acknowledgements: This paper is based on the data of the Master's thesis entitled "Determination of earthquake response of existing masonry buildings in the case of an education building". The thesis was prepared by İhsan Kasım Karataş and was supervised by Assoc. Prof. Baris Yildizlar. The third author, Baris Sayin, put a lot of effort into data curation, conceptualization, and methodology.
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Peer Review: Externally peer-reviewed.
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RESEARCH ARTICLE

Exploring Daily Tour Routes in Historical Peninsula by Using Generative Design

Merve Deniz TAK[1], Naime Hülya BERKMEN[2]

[1]Res. Assist., Istanbul University, Faculty of Architecture, Department of Urban and Regional Planning, Istanbul Türkiye
[2]Prof. Dr., Istanbul University, Faculty of Architecture, Department of Urban and Regional Planning, Istanbul, Türkiye

ABSTRACT
In this study, with the help of a generative design, daily routes were created and optimized in light of certain objectives within the scope of the Historical Peninsula of Istanbul, especially in areas containing monumental structures and defined as world heritage sites. The current cultural-historical tours in the historical peninsula mainly focus on the main points such as Sultanahmet Square and its surroundings, Topkapı Palace and its surroundings, and the Grand Bazaar. However, within the scope of the peninsula, approximately 12,000 registered buildings (Istanbul Historic Peninsula Management Plan, 2018) are located on the Marmara Walls on the seven hills line, Land Walls, Golden Horn shores, and in each sub-region within its own urban texture. In this context, it is aimed to reveal the different route potentials within the protected areas that should be seen in the peninsula as a whole. In the study, road widths and topographical data which are two of the important parameters that constitute the original texture, and the areas that need to be seen at distances that can be visited daily were taken into consideration. In the whole historical peninsula, 9 different sightseeing routes were determined, the starting point of these routes and one mandatory stop for each route were defined, and the routes were optimized with single-objective optimization for walkability and exploration of the historical texture as much as possible. With this method, a decision support tool is provided for decision-makers such as city planners, tour guides, and travelers themselves.

Keywords: İstanbul Historical Peninsula, generative design, single objective optimization, decision support tools

Introduction

The Historical Peninsula has been the subject of studies from many different perspectives in the historical process with its historical, cultural, and natural qualities. The diversity offered by the area, its quantitative values, its spatial size, population density, and mobility bring up many potentials as well as problems that need to be solved.

The Historic Peninsula, with its residential areas, working areas, and especially the only center of the metropolitan area until the 1960s (the area where the traditional center is located today) has precious monumental buildings, civil architecture examples, and silhouettes due to its topography. These areas need to be protected and these are the points that should be seen for tourism in this context. In the Peninsula, there exist many tourism and promotion routes that have been determined both by the relevant municipality, various institutions, and non-governmental organizations. These routes are predominantly around certain monumental buildings and their surroundings but may be limited to Topkapı Palace, Hagia Sophia, and Sultanahmet. Apart from these routes, there exist also thematic sightseeing routes organized in the area.

However, these routes cannot be diversified according to user preferences and are not customized according to the user's accessibility ability or the regions they want to focus on.

In this study, a methodological experiment was carried out to create new routes that are customized by decision-makers in the Historic Peninsula. These routes mainly take into account the World Heritage sites but also integrate the heritage sites and other must-see points of the peninsula. The research question of this study can be summarized as "To create the ideal route specific to the demands of the decision-maker, with the help of decision support tools; the decision of which destinations and paths to be used is made, and alternatives are generated." In this method experiment, Geographical Informations Systems, and generative design tools were used by the decision maker to identify potential sightseeing destinations and create optimal routes under desired

Corresponding Author: Merve Deniz TAK **E-mail:** mdtak@istanbul.edu.tr
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conditions. The features of road structure according to road width and slope were identified with GIS and after, these attributes of roads were used for generating potential routes between potential destinations.

Computational Design As A Tool For Decision Making

From the perspective of complex system theory, it can be said that cities are complex systems due to the intersection of subsystems like transportation, ecology, humans, infrastructure, and social systems (Alberti, 2008; Batty & Marshall, 2012). This complexity creates non-linearity, unpredictability, and numerous possibilities for various actors in the city (Portugali, 2018). In this context, decision-making becomes a hard process for decision-makers. Decision support systems help the decision-makers adapt to this complex process by data collecting, analyzing, visualizing, and creating fast, adaptable, flexible solutions. Decision support systems have the potential to significantly reduce the amount of time required to solve the problem, as well as decrease the amount of resources and materials that are wasted in the process (Chan et al., 2016). Although computer programs are the first thing that comes to mind when it comes to decision support tools, a computer-based system, human power, or a combination of them can be the decision support tool for the decision-maker. But mostly, Geographical Information Systems (GIS) and Computer Aided Design tools are the most commonly used computer-based decision support tools in urban-related problems.

Decision-making is defined as the process of finding the optimal solution for a goal (Sugumaran & Degroote, 2020). But in complex systems, finding an ideal can be hard with only human power and it needs computer science to manage this level of complexity. In this study, first of all, the existing structure of the urban layout was understood by using GIS, which is a decision-support tool, and then ideal solutions were produced by using computational design and AI-assisted optimization, which is also a decision-support tool.

Computational design is subdivided into many sub-headings, but parametric and generative designs are the most common terms used in the literature (Lee, 2015). They are often intertwined in the literature. For parametric design, it can be stated as designing the production process, not the product itself, by defining certain parameters and obtaining multi-alternative outputs (Lee, 2015). Thanks to the definition of these parameters, when the final product is not desired or when the condition changes, it allows individuals to quickly return to the design phase and produce new results suitable for the new condition. This fast adaptation capability makes parametric design valuable for solving complex problems. Generative design has very similar features to parametric design, but with a slight difference - it uses AI-based methods for optimization goals (*Generative Design 101*, n.d.). Thanks to the generative design, the options that are important for the decision-maker are identified in a very short time and suitable results are generated. In this way, the decision maker can reduce the total effort by shaping the process instead of producing the design one by one and they can have much more control over the possibilities by choosing among the solutions.

Methodology

As the traditional center of the Istanbul metropolitan area, the Historic Peninsula is not limited to the metropolitan area, it is Turkey's most important tourism destination. In particular, the area between Atatürk Boulevard and Topkapı Palace on the east-west extension, the Sultanahmet and Hagia Sophia Mosques, and the Grand Bazaar area are known to both mass tourism and independent tourists. The defined area is especially preferred for one-night stays and covers a significant portion of the literature related to the peninsula. However, the historical and architectural values that must be seen, which belong to the entire peninsula, are not limited to this area. New cultural routes have been added in the recent historical process. With the studies conducted in the area, new values have been discovered (such as Yenikapı, cisterns, etc.), and with the restoration of monumental and civil architectural examples and street improvements, new potential routes have emerged in the area.

The availability of parking spaces and easy access using vehicles are important factors in the preference for these frequently visited places. However, visiting many places in the Historic Peninsula can only be possible on foot after a certain point. Walking in areas with a certain slope after exiting the metro, tram, bus, etc. stations public transport vehicles can be challenging and not preferred considering health and age status. Therefore, the topography and width of the roads were analyzed and became an input for binding many valuable destinations.

The aim was to create multiple routes to be visited and seen in the whole of the Historic Peninsula, focusing on the World Heritage Sites. To create these routes, especially the transportation and topography analyses of the area were made and alternative criteria were determined based on these analyses. In the relationship between topography and accessibility, it was aimed to create routes that can cover both the original texture of the area and the World Heritage Sites and other points to be seen. For this purpose, in this study, road width and the slope of the roads were determined as parameters of the design process. In this context, the existing transport infrastructure was analyzed according to road width and the slope of the road in the ArcGIS Pro program. Although the accessible road slope in the daily life of people is accepted as approximately 8%, the maximum slope that tourists can walk comfortably in long-term walks, considering different age groups, is stated as 5%. In this study, roads with a slope of 5% were determined as the upper limit for comfortable traveling, and areas with a slope of 5% and less than 5% were accepted as ideal roads in the design process. In addition, another parameter is the roads with widths of 5 m or less. Roads under 5 m wide are concentrated in the traditional texture of the peninsula, where both parcel size and civil architecture examples are concentrated. Roads with a road width of more than 5 m are considered as roads that are more comfortable to travel on as cars share the road with pedestrians in most of the peninsula.

After defining the road features, three scenarios were established with different starting points and mandatory destinations. A total of nine alternatives were created for these three scenarios based on the road features used in the travel routes. The alternatives generated for 3 different scenarios were i) maximizing the use of roads with a slope ≤ 5% and width >5 m, ii) maximizing the use of roads with a slope ≤ 55% and width ≤ 55 m, iii) the shortest path without any preferred road features. After structuring the algorithm, the alternatives were optimized by Rhino Grasshopper's Galapagos plug-in as single-objective optimization.

Overview of the Historical Peninsula

The province of Istanbul is located at the junction of the Asian and European continents, within the Marmara Region, one of the seven geographical regions of Turkey, and forms a transition between the Balkan Peninsula and Anatolia. It is topographically bounded by the Black Sea to the north, the high hills of the Kocaeli Mountain Range to the east, the Sea of Marmara to the south, and the water dividing line of the Ergene Basin to the west, and administratively by the provinces of Kocaeli to the east and Tekirdağ to the west. The Historic Peninsula is located between 41° 02' north latitude and 28°55'34 east longitude. Located at the southeastern end of the Çatalca Peninsula, the Historic Peninsula forms a unique geography shaping the entrances of the Bosphorus and Golden Horn to the Marmara Sea. The area is bordered by the Golden Horn to the northeast and the Beyoğlu coast to the south, the Sea of Marmara to the south, Eyüp to the north, Zeytinburnu to the west and Bayrampaşa to the northwest (Figure 1).

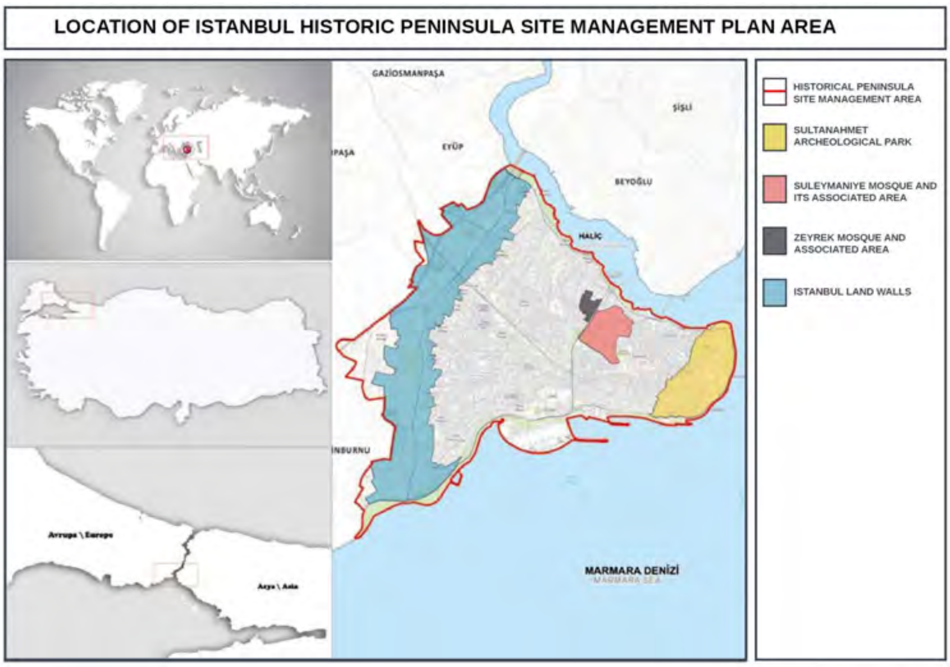

Figure 1. *Location of the Historic Peninsula Management Plan (Istanbul Historic Peninsula Management Plan, 2018)*

The Historic Peninsula as a whole, excluding the Yenikapı Embankment Area, is a protected area and its four World Heritage Sites were inscribed on the World Heritage List in 1985.

Areas in the Historic Peninsula on UNESCO's World Heritage List have been listed as:

- Sultanahmet Urban and Archaeological Conservation Area (The Archaeological Park)
- Süleymaniye Mosque and its Associated Conservation Area
- Zeyrek Mosque (Pantocrator Church) and its Associated Conservation Area

- Land Walls of Istanbul (Figure 2)

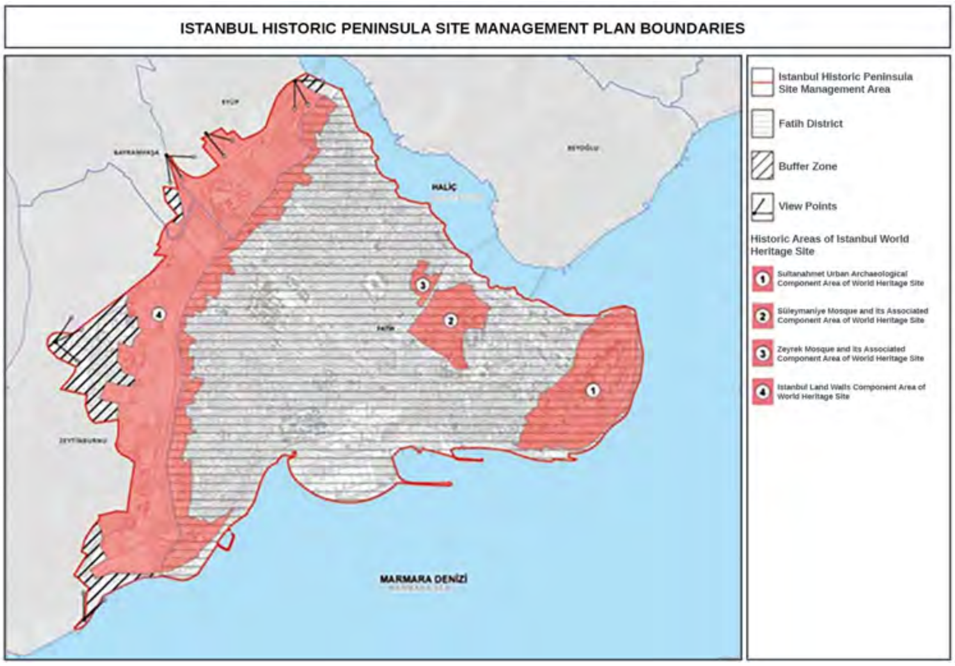

Figure 2. *Boundaries of Istanbul Historic Peninsula Management Plan (Istanbul Historic Peninsula Management Plan, 2018)*

Table 1. *Historic Peninsula Walled City Area (IMM,2018)*

Region	County name	Area (Ha)	Ratio (%)
Historic Peninsula Walled City	Fatih	1557	71.82
	Yenikapı Embankment Area	58	2.67
	Total	1615	74.49

The Historical Peninsula, as the study area, encompasses the entire Fatih District, with an area of 1,557 hectares, excluding the Yenikapı filling area. When considering this size and the densities of the night and day visitor population, functional areas, and transport transfer areas it exhibits a very dynamic and mobile structure. The night population of the area in 2022 was approximately 400,000, while the daytime population exceeded 2 million. In this context, the creation of routes to be traveled in line with the assumptions of the historical environment, which is the subject of the study, is challenging compared to relatively quieter historical environments. The presence of the most important and largest health, education, and administrative institutions and organizations in the metropolitan area and the entire of Turkey, cause vehicle and pedestrian traffic to overlap, making it difficult to create comfortable walking routes. This makes the search for more comfortable traveling routes with new technologies even more important.

Current Road Structure In Historical Peninsula

In the first stage, the current situation of the road structure was examined according to the road width and slope. First-stage analyses were made using the ArcGIS program. To calculate the slope of the road structure, firstly, areas with a slope of more than 5% were defined. Next, the current road structure and the areas with a slope of more than 5% were overlaid and the roads were divided according to this intersection. As a result, it has been seen that 72.5% of the road structure is located on areas with slopes under 5%.

In addition to the slope, road widths were also classified according to road width. First, roads with a width smaller or equal to 5 m, which have a historically rich texture, were determined. In the second part, roads with a width larger than 5 m, which are easy to travel on according to the defined pedestrian roads, were ascertained.

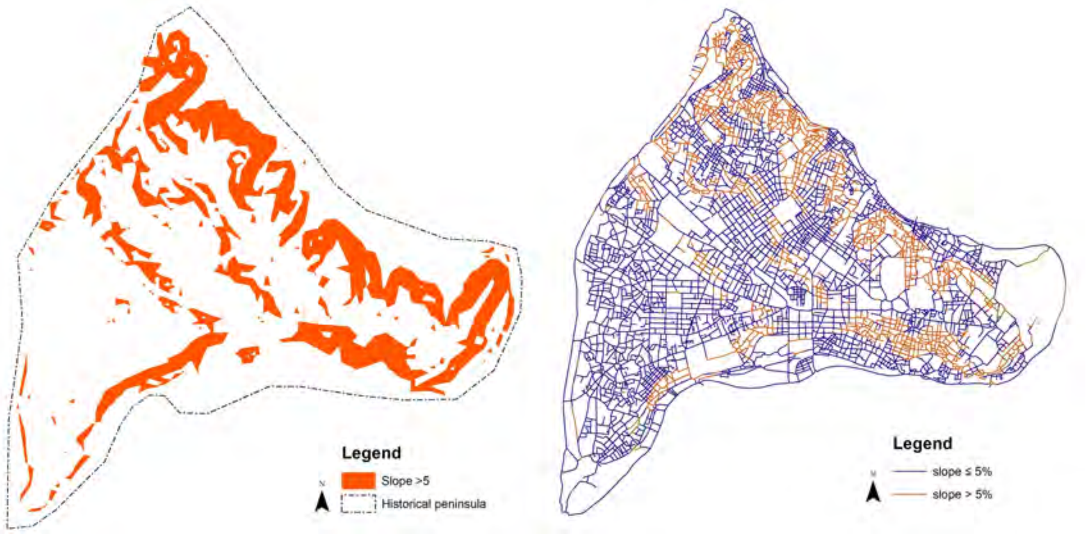

Figure 3. *Slope and road structure according to slope in Historic Peninsula*

Figure 4. *Road structure according to road width in Historic Peninsula*

As a result, the study found that 36.87% of the entire road network has ideal conditions for easier traveling, and 35.71% of them have ideal conditions for exploring the historical textures in the peninsula.

In the final stage of the study, the researchers applied an optimization study to prioritize the use of these roads in the generated routes.

Table 2. *Ratio of roads' features*

		ROAD WIDTH (%)	
		≥ 5	< 5
SLOPE (%)	≤ 5%	36.87	35.71
	> 5%	16.93	10.49

In the second stage, this road structure was used as input for route decision-making. To create the walking route, 14 main historical places were defined: Spice Bazaar, Grand Bazaar, Yedikule Fortress, Fener-Balat region, Samatya region, Kumkapı region, Süleymaniye Mosque, Beyazıt Square, Tekfur Palace, Bukoleon Palace, The Prison of Anemas, Kariye, Ayios Church region, Fatih Mosque, Zeyrek region, Sultanahmet region. These destination points were used in the algorithm as the potential destinations to select for generating optimized routes.

Figure 5. *Süleymaniye Mosque and Topkapı Palace (Istanbul Historic Peninsula Management Plan, 2018)*

Figure 6. *Fener Balat Region (Istanbul Historic Peninsula Management Plan, 2018)*

Figure 7. *Istanbul Land Walls and Yedikule Fortress (Istanbul Historic Peninsula Management Plan, 2018)*

To generate walking routes, three scenarios were decided on based on important historical destinations. The first scenario started at Yedikule Fortress and included The Prison of Anemas as a mandatory destination. The second scenario started at the Sultanahmet region and included the Sülemaniye region as a mandatory destination. In the last scenario, the Sultanahmet region was again chosen as the starting point, and the Fener-Balat region was the mandatory destination. These destinations were chosen for their historical significance and to create variety in the generated routes.

Algorithm

Finding the optimum option among the destinations and creating the most ideal route becomes a time-consuming and difficult process with human abilities alone. Therefore, at this stage, generative design was used as a support system for the decision-maker, so that alternatives that may be invisible to humans can be presented to the decision-maker in a very short time. Rhino's Grasshopper plug-in for the visualized algorithm was used as the generative design tool. First, destinations were defined in the program and then a random selection from these destinations was interpreted by the system as a parameter in the optimization. For random selection, a search space ranging from 4 to 8 on each route was determined. These numbers are an assumption taken from official travel routes in the Historical peninsula for an average travel route destination list. Then, to create the route between these stops, the road structure analyzed in the ArcGIS program was defined in Grasshopper with its features like slope and road width. The road structure, which was divided into 4 different classes according to slope and width, formed the input for the route creation. Between these destinations (with defined starting points), traveling routes were generated by selecting the shortest path. To determine the shortest path, the ShortestWalk plug-in was used which is a plug-in that includes the A* search algorithm. A* search algorithm is one of the heuristic AI algorithms that is mostly used in games or map applications for finding the shortest path. It is known for its calculating speed to generate fast results (Isaac computer science, n.d.).

Although the travel routes were created, the research question had not been fully explained, which was to find the "ideal" route based on both accessibility and comfort while exploring historical places. However, finding the best possible alternative in a complex urban system is generally a tough issue due to the need of controlling and calculating all parameters at the same time. This search process to find the optimum route with some constraints is generally named optimization (Küçükkoç, 2020). This process can be divided into two headlines according to their objectives: single-objective optimization and multi-objective optimization. In single optimization, the main goal is maximizing or minimizing the defined objective value with its constraints. On the other hand, multi-objective optimization deals with more than one objective. In this complexity, the best for one objective may be the worst for another, therefore, there can not be only one optimal goal in this optimization problem; there exists a set of optimal solutions (Sarker & Newton, 2007). In this study, the solution to the research question was generated as a single-objective optimization.

In the first stage, after identifying the features of the roads that were used by the generated exploring route, the maximization of the roads that will provide the most comfortable traveling experience was defined as the optimization problem. For this purpose, 3 optimization setups were made. First, roads with a slope smaller than or equal to 5% with a width larger than 5 m, which have the maximum percentage in the route for a comfortable journey, were selected. The experiment aimed to maximize the use of these roads by changing the number and locations of stops to be visited. Second, by using the defined mandatory stops, the question "Which destinations would be visited in the optimum shortest time without any road restrictions" was also optimized and alternatives were produced for the decision-maker. The final scenario was designed to enable maximum exploration of the historical structures of the peninsula, by using a road width smaller than or equal to 5m and a slope smaller than or equal to 5%.

Experiment Results

For 3 destination purposes, 9 different route optimizations were made in total. The first optimization group's obligatory destinations were defined as Yedikule Fortress and The Prison of Anemas, the latter of which is the starting point. Three different optimizations were made in this group. The first optimization in this group was defined as using a road slope less than or equal to 5% and a road width of more than 5 m while generating the alternatives. As a result, optimized route 1 selected 4 destinations: Yedikule Fortress, Bukoleon Palace, the Spice Bazaar, and the Prison of Anemas. The total length of the route was calculated as 11.2 km and the ratio of the slope was less than or equal to 5 and 73.5% of the roads had a width of more than 5 m. In addition to these destinations, even though the algorithm selected only 4 destinations, the traveling route is also fairly close to the Samatya region, Sultanahmet region, and Fener-Balat region. Thus, it can be said that this route contains 7 destinations.

The second optimization in this group was analyzed with the aim to maximize passing through narrow streets where the historical texture is dense. As a result, the route was calculated as 7.9 km. The proportion of roads with a slope less than or equal to 5% and a width less than 5 m was 49.4%. The proportion of roads with a slope is less than or equal to 5% and a width greater than 5 m was 34.7%. The destinations in this scenario were generated as the Prison of Anemas, the Ayios Church Region, the Samatya Region, the Fener-Balat Region, and the Yedikule Fortress.

The final optimization in this section was analyzed as an answer to the question "How would the mandatory stops of the first route be followed if they were to be reached in the shortest time without any road restrictions?" The route length was 6 km. The proportion of roads with a slope less than or equal to 5% and a width less than or equal to 5 m was identified as 48%; the proportion of roads with a slope less than or equal to 5% and a width greater than 5 m was identified as 34.4%. The destinations in this scenario were generated as Tekfur Palace, the Prison of Anemas, the Ayios Church Region, and Yedikule Fortress.

The second optimization group, the Sultanahmet Region was taken as the starting point and Süleymaniye Mosque as the mandatory destination. The optimization rules were determined like with optimization group 1. As a result, the first optimization destinations were determined as Topkapı Palace, Sultanahmet Region, Bukoleon Palace, the Grand Bazaar, Beyazıt Square, the Spice Bazaar, the Süleymaniye Region, and the Ayios Church Region. The route length was 13.3 km. The ratio of the road slope ≤5% and the road width of more than 5 m was 67%. In the second optimization, the route length was calculated as 10.1 km. The roads with a slope of ≤5% and a width of ≤5 m were 42%. This route's destinations are the Fener-Balat Region, the Ayios

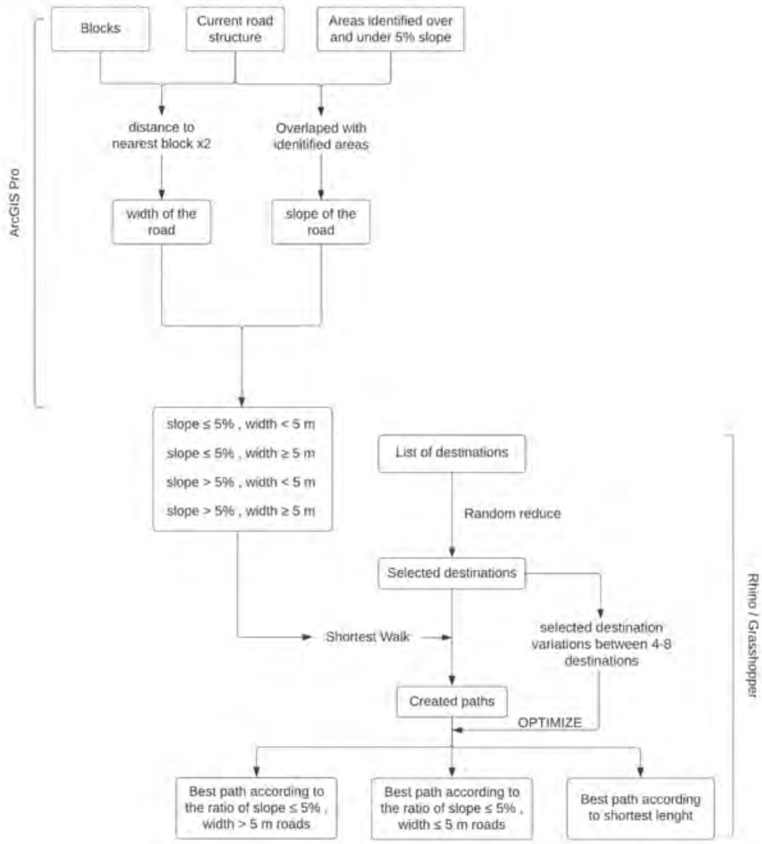

Figure 8. *The structure of the algorithm*

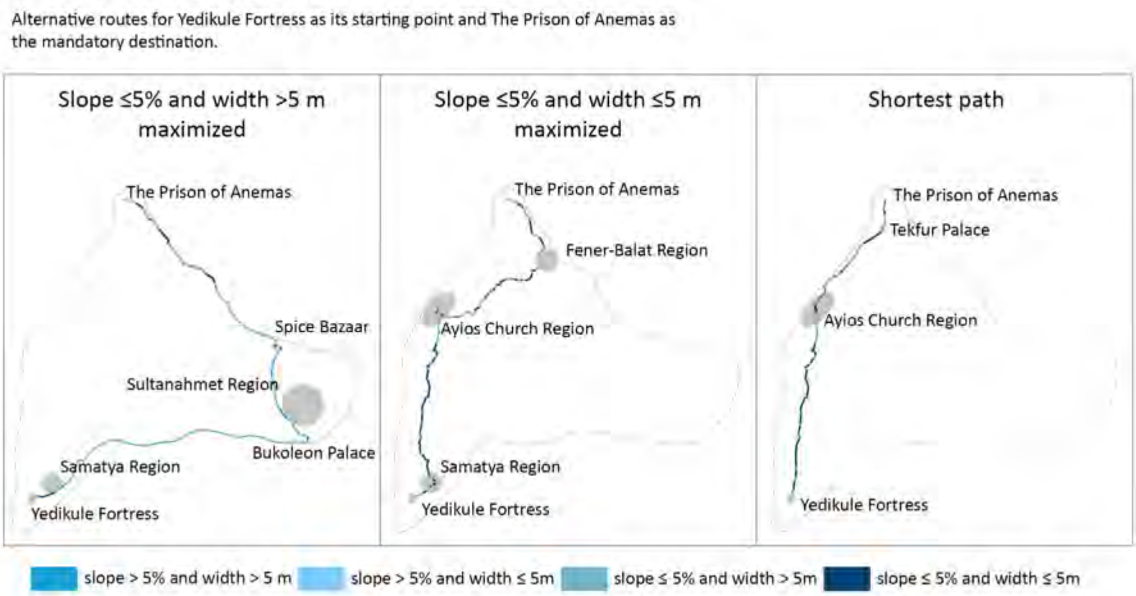

Figure 9. *Alternative routes for Yedikule Fortress as the starting point and the Prison of Anemas as the mandatory destination*

Church Region, the Samatya Region, Süleymaniye Mosque, and the Sultanahmet Region. In the last optimization, the route length decreased to 2.2 km and the destinations are Süleymaniye Mosque, the Grand Bazaar, Beyazıt Square, and the Sultanahmet Region.

For the last optimization group, the Sultanahmet Region was defined as the starting point with the Fener-Balat Region as the

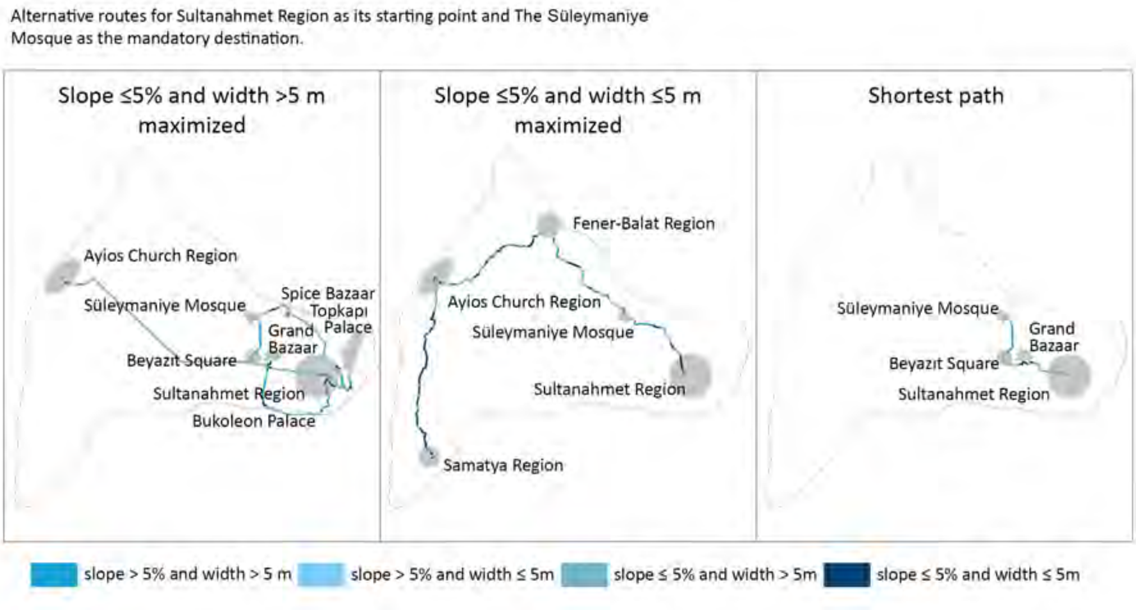

Figure 10. *Alternative routes for the Sultanahmet Region as the starting point and Süleymaniye Mosque as the mandatory destination*

mandatory stop. In the first optimization of this group, the length of the route was generated as 8.8 km. The ratio of the roads whose slope was smaller or equal to 5% and whose road width was more than 5 m was calculated as 76.9%. The destinations on this route are the Fener Balat region, the Fatih Mosque-Zeyrek Region, the Sultanahmet Region, and Bukoleon Palace. For the second optimization, the algorithm generated a 10 km travel route and determined the Fener-Balat Region, the Ayios Church Region, the Samatya Region, and the Sultanahmet Region as destinations. Roads with a slope ≤5% and width ≤5 m was 46.2%. In the final, shortest route optimization, destinations were defined as the Fener-Balat Region, the Fatih Mosque-Zeyrek Region, Beyazıt Square, and the Sultanahmet Region. In addition to this, because the Grand Bazaar is close to Beyazıt Square, it can be said that this route also includes the Grand Bazar with a little bit more effort. The length of this route was calculated as 4 km. The ratio of road slope ≤5% and width ≤5 m was 16% and road slope ≤5% and width >5 m was 69.4% in this route.

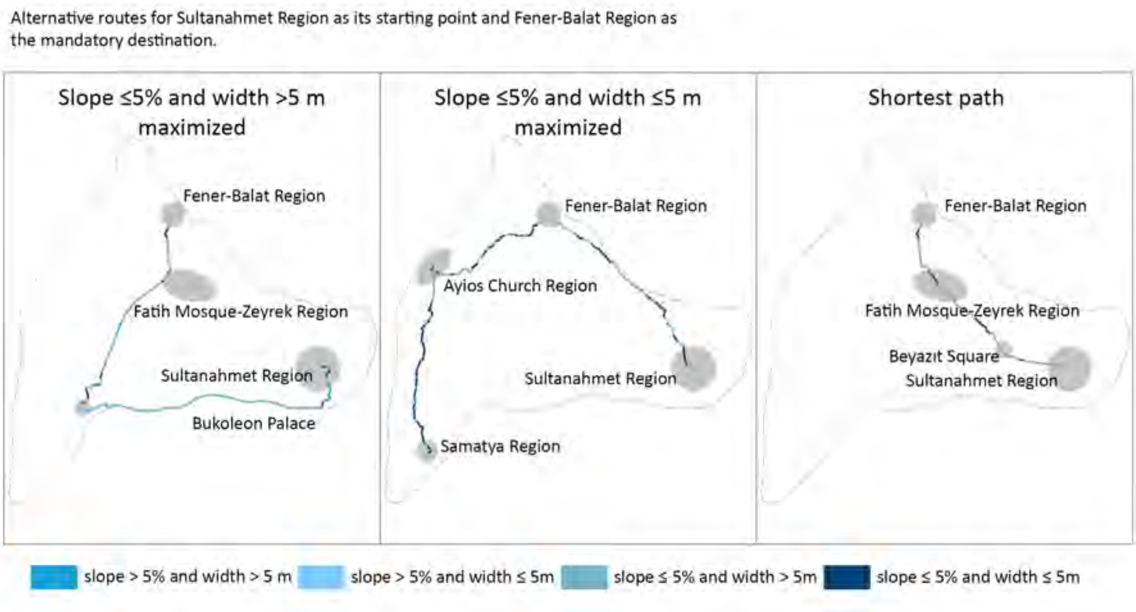

Figure 11. *Alternative routes for the Sultanahmet Region as the starting point and the Fener-Balat Region as the mandatory destination*

Table 3. *Summary of alternative routes*

	Group 1 (Starting point Prison of Anemas and Yedikule Fortress as obligation)			Group 2 (Strating point Sultanahmet Region and Süleymaniye Mosque as obligation)			Group 3 (Starting point Sultanahmet Region and Fener-Balat Region as obligation)		
	slope ≤5% and width > 5 m maximized	slope ≤5% and width ≤ 5 m maximized	shortest path	slope ≤5% and width > 5 m maximized	slope ≤5% and width ≤ 5 m maximized	shortest path	slope ≤5% and width > 5 m maximized	slope ≤5% and width ≤ 5 m maximized	shortest path
Total length of the route (km)	11.2	7.9	6	13.3	10.1	2.2	8.8	10	4
Ratio of slope > 5% and width > 5m roads (%)	8.2	2.9	10.8	12.6	11	20.3	6	3.6	5.1
Ratio of slope > 5% and width ≤ 5m roads (%)	7.4	12.8	6.2	8.5	18.9	9.8	6.5	15.5	8.7
Ratio of slope ≤ 5% and width > 5m roads (%)	73.2	34.7	34.4	67.2	27.1	58.6	76.9	34.4	69.4
Ratio of slope ≤ 5% and width ≤ 5m roads (%)	10.9	49.4	48.4	11.5	42.8	11	10.4	46.2	16.6

Limitations

The study focuses solely on travel routes that can be formed using the existing road system. However, when creating a travel route, various factors such as road safety, aesthetics, materials, design, etc. can also be considered in addition to the destination and road system. Plus, the number of destinations to be selected is assumed to be in the range of 4-8, considering the size of the destinations and the average number of stops on a general travel route. Beyond these assumptions, more options can be offered to the user and routes can be developed with different priorities.

Conclusion

As it is known, the Historic Peninsula has a very complex structure, and as a place that was the capital of three empires, it bears traces of quite different periods both underground and above ground. However, especially the area between Atatürk Boulevard and Topkapı (Old Eminönü), Topkapı Palace, Sultanahmet, the Grand Bazaar, the Spice Bazaar, and the Basilica Cistern are the better-known areas that first come to mind. Those who stay for 1 or 2 nights to see the city visit these areas first with official tours. However, in addition to these classical Istanbul routes, there are also very important historical and cultural routes, scenic spots, architectural examples on a single building scale, routes, and areas that reflect the original texture and past identities.

In this context, with this study, different alternatives have been explored by pointing out the points that are overshadowed by the Sultanahmet, Topkapı, and Eminönü regions but should be seen. For this exploration, generative design tools were used as decision support tools with the help of GIS. For 3 different objectives (maximizing the use of roads wider than 5 m, maximizing the use of roads narrower than 5 m, and minimizing the route length), a total of 9 alternatives were optimized with different destinations. Some of the generations have been directed in such a way that the tourist can discover other regions of the peninsula while visiting the most famous ones, while others have been directed to explore the rest of the peninsula except for the Sultanahmet-Topkapı-Eminönü regions.

For future studies, these tools can be improved through user application and can shape the routes according to the demands of the traveler and show them the ideal alternatives by using many parameters that should be taken into consideration by the decision maker. This support system can be used not only for individual use but also at the municipality scale, by determining the potential routes of tourists, focusing on these routes for a more comfortable journey, and developing special designs for these routes.

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RESEARCH ARTICLE

Cellular Automata-Based Suitability Analysis for Dense Urban Areas: The Case of Istanbul

Emirhan COŞKUN[1]

[1]Haliç University, Faculty of Architecture Department of Architecture, Istanbul, Türkiye

ABSTRACT
Cellular automata (CA) have emerged as one of the most popular approaches used in recent years to evaluate and predict the development and transformation of cities. Cellular automata approaches have made the complex interaction between urban dynamics and urban sustainability effectively understandable. These models provide a deeper understanding of the complex relationship between land-use changes and urban sustainability. This understanding enables governments, planners, and stakeholders to predict and evaluate the potential consequences of future policy alternatives. It is essential to create scenarios in determining urban policies. The fact that cellular automata models create what-if scenarios makes it an approach that can be used frequently for urban transformation. Thus, the study focuses on the urban development paradigm by interpreting the urban transformation concepts in the historical coastal areas of Istanbul with geospatial techniques, a CA-based urban growth model, and land use data. Reliability is vital for using CA models as decision-support tools in this context. Testing the reliability of CA models, one of the study's aims, is an essential parameter in this respect. For this purpose, the CA model was created by collecting population density, focal points, distance to roads, land uses, and land slope data from different periods (1994 and 2006). The results demonstrated that urban simulation models are effective decision-support tools, promising a more inclusive and explicit planning process.

Keywords: Decision support systems, urban growth, cellular automata, GIS

Introduction

The urban growth model, an interdisciplinary research area, emerges as an important theoretical and practical research area. Social, economic, and political interactions change and transform the physical space. As a result, many cities go through the restructuring process with new roads, infrastructure improvements, and economic purposes. For the sustainable distribution of usable resources, it is necessary to understand the dynamics of the urban growth process and to establish urban growth models according to these dynamics (Batty, 2005; X. Liu et al., 2017; Tripathy & Kumar, 2019).

Understanding urban development requires analyzing the complex relationships that make up urban interactions. This network of relations, which triggers urban change, determines the city's transformation. Since this is a complicated process to define, applying models that will help us to use urban dynamics interactively may allow us to remove the complexity (Sipahioğlu & Çağdaş, 2022). If all the decision makers of urban development and transformation, such as government, planners, stakeholders, etc., are integrated, it will be possible to create a suitable approach. The approaches we use in the computing age have a structure that can integrate with the urban development problems mentioned. One of the approaches that can support urban development studies is the CA model. In this context, the study focuses on understanding the urban growth process, making simulations, and measuring the reliability of CA models.

CA has emerged as a suitable urban modeling technique offering a powerful simulation tool to predictand comprehend the complexity of urban systems over space and time (Aburas et al., 2016; Musa et al., 2017; Santé et al., 2010). CA has been widely used for urban development due to its ability to adapt to complex spatial areas, achieved using simple and effective rules. This feature of CA gives it significant advantages. The general features of CA can be listed as follows. (1) CA is an intermittent dynamic system, and due to this structure, it represents complex and dynamic spatial models or is constantly effective in testing its performance (Sietchiping, 2004). (2) The spatial integrity of CA provides an advantage in any geographical area or self-organization, and thus it is possible to reach high-quality outputs (Silva & Clarke, 2005). (3) The adaptability of CA includes the flexibility of its relations

Corresponding Author: Emirhan COŞKUN **E-mail:** emirhancoskun@halic.edu.tr
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with neighboring cells and the size of the cells. In addition, the state of being integrated with different models can be shown as an expansion (Batty, 2005). (4) The simplicity of CA allows it to present spatial complexity intuitively and effectively. At the same time, considering it in the city context reduces the complexity to a level that is easy to handle (O'Sullivan & Torrens, 2001). (5) The lattice structure of CA makes its connection with geographic data completely visual. Due to its character, it can integrate with many virtual applications. In the urban context, CA has a structure that allows monitoring the growth of urban systems over time.

Many applications are created by taking advantage of the convenience and flexibility of CA. CA has four main ways to use in the urban context or to show a developing structure in regions with different urban dynamics. (1) Generating much richer forms of degeneration at the level of individuals: To understand the situation of any urban dynamic at different scales, it is necessary to analyze the individual layer. This is possible by considering spatial areas of different scales as cells and evaluating individuals (such as population and land uses) as factors. Thus, CA cells will encounter different situations at different scales, and sufficient data can be obtained about urban dynamics (Silva& Clarke, 2005). (2) Adaptations of CA Formalism: Changes to CA models or the adaptation process into which the models will enter include changes in the sizes and structures of the cells that make up the model. In addition, cellular states that can expand and extend neighborhood relations also have an important place (Batty, 2005). (3) Increasing the Efficiency of CA Models in the Optimization and Calibration Process (Efficiency and Improvement of CA Models, especially in the Optimization and Calibration Process): Studies on the development of optimization and adjustment play an essential part in this context (O'Sullivan & Torrens, 2001). (4) Linking CA Models to Traditional Cross-Section Approaches such as Transportation Models: Despite all the developments in CA Models, the limitedness of CA, the number of neighborhood functions, and the inertness characteristics are essential to discuss (Sietchiping, 2004).

Cellular automata models can integrate into geographic information systems and simulate complex urban dynamics by processing remotely sensed data with simple rules. These features of cellular automata; combined with the parameters of simplicity, flexibility, and controllability; make it an effective tool that combines spatial and temporal dimensions in urban development processes (Musa et al., 2017; Santé et al., 2010; Yeh et al., 2021). In urban studies, cellular automata show a feature with more potential than agent-based models (Table 1) (Wu & Silva, 2010). One of the critical factors is that it can easily integrate with geographic information systems (GIS). Integration with GIS facilitates using local data to make complex calculations encountered in urban dynamics, resulting in more effective results than mathematical models (Musa et al., 2017).

Table 1. Comparison of CA and Agent-Based Systems (Wu & Silva, 2010).

	CA	Agent-Based Systems
Focus	City-level and regional level Landscape and transition Urban simulations	Household and family; vehicles Human actions Population dynamics
Status change	Exchange data with neighborhoods Navigation	Alter attributes and behaviors by themselves
Mobility	Immobile entities	Mobile entities
Representing	Spatial dynamics Geographic factors	Aspatial Dynamics Social-economic factors
Character	Affinity with raster data and GIS Evolution Systems	Freedom for proper spatial mobility Complex Systems

Urban simulation models are considered decision support systems due to the complex nature of urban systems, incomplete or inaccurate local data, and uncertainties in planning policies introduced by all stakeholders involved in the urban design process (Poelmans & Van Rompaey, 2010; Yeh et al., 2021; Yeh & Li, 2006). These models aim to establish a process for how a city will transform concerning urban growth (Camacho Olmedo et al., 2018), allowing us to comprehend urban dynamics in advance and create development scenarios. The cellular automata approach is similarly unconcerned with the cause of urban growth and instead provides results for understanding how urban growth occurs. This study was motivated by the need to analyze the trend of urban growth and comprehend its future consequences by investigating the transformation and spatial changes of Istanbul's urban coastal areas, which have undergone dramatic changes due to urban policies and social and economic transformation. The region where the most significant change in Istanbul's urban coastal areas has occurred is the Marmara Sea coast between the Historical Peninsula and Atatürk Airport. The land use changes due to the filling areas made in the 2000s, the acquisition of new urban areas, and neo-liberal urban policies have been influential in determining the study area (Usanmaz Coşkun, 2020). In this context, the area between the historical peninsula and the airport was determined by creating a 10 km buffer zone (Figure 1).

Figure 1. Study Area.

Method

CAs are computational tools that simulate complex systems through simple rules. It is a system of cells representing a particular moment and local interactions through rules based on the current state of adjacent cells (Chakraborty et al., 2022; Y. Liu & Feng, 2012; Mantelas et al., 2012). The ability of CA to represent spatial dynamics and to incorporate time into the process are essential advantages in urban growth models. The spatial and temporal characteristics of CA make it easy to be an analysis tool for GIS systems. Before moving on to urban studies, defining the cell structure (the smallest unit of CA) is crucial to understand the model. Each cell that composes the cellular fields contains features belonging to one of the certain predefined states. The rule that provides the transition between states is defined as the local rule. Optimizing the transition rules according to the urban scenario for the cellular automata model is essential. This process is known as calibration. Since the finite state machine of a cell receives input from the neighboring cell, a local rule definition is crucial. Neighborhood refers to other cells in the adjacent position of a cell that can cause or influence the cell to move to the next state. For this reason, local rules represent transitions between states that will produce different results for different situations (Chakraborty et al., 2022; Puente et al., 2015).

Cell space, cell, neighborhood, time states, and transition rules form the essential components of a CA model. In urban models, each component has geographical effects and reflections. In urban models, the cell area represents the two-dimensional geographical area brought together by the cells, while the states of the cells indicate different land uses. Transition rules provide transitions between states with different land uses. Transition rules also form the core of the CA model. The autonomous structures of cells enable cells to change state according to transition rules as time progresses (Hashemi & Meybodi, 2009; Wu & Silva, 2010; Triantakonstantis & Mountrakis, 2012; Yeh et al., 2021) (Figure 2).

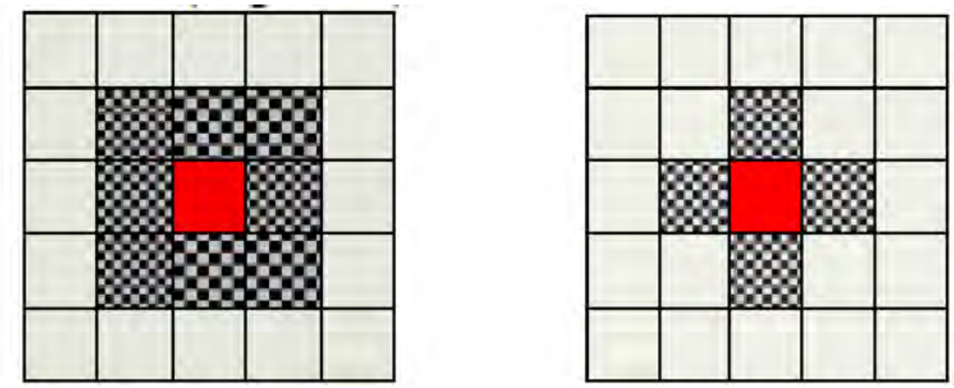

Figure 2. Neighborhood in Cellular Automata Cell. Left: Moore neighborhood; Right: von Neumann neighborhood (Hashemi & Meybodi, 2009, p. 413).

In a basic CA model, a regular grid system of square cells allows computation and works in harmony with the remotely sensed data. When the neighborhood of the cells is homogeneous, the hexagonal cell system can be used instead of the grid system. 3D cell systems can simulate vertical developments in urban systems. As in Voronoi systems, cell types with irregular areas can be used for scenarios with different spatial values (Iovine et al., 2005; O'Sullivan & Torrens, 2001; Shi & Pang, 2000; Yeh et al., 2021) (Figure 3).

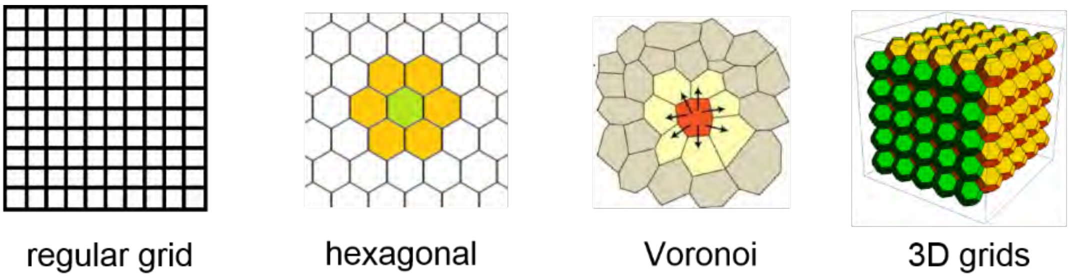

Figure 3. CA Grid Types (Wallentin, 2020, p. 97; Wolfram, 2002, p. 159).

Factors such as urban dynamics, changes in land uses, physical conditions, transportation, and population create complex neighborhood relations. Using non-uniform cell areas may occur because the variables are effective in urban models. The fact that transition rules form the core of cellular automata is vital to consider when describing complex relationships. In a basic CA model, the transition rules depend only on the state of a cell and its neighbors. However, in urban models, the large number and complexity of urban dynamics require consideration of external factors in addition to the states of neighboring cells. The flexible nature of CA models allows us to make these changes. While constructing the model, the randomness of urban growth and urban theories adopted throughout history can be reflected in the model. Another point is that the transition rules in basic CA models are static. It is the same at every moment of the model. Since urban processes change over time, it reveals the necessity of changing and calibrating the transition rules depending on the time factor (Li et al.,2008).

The simple and ordered nature of cellular automata models may need to be revised to represent the real world where geographic data is concerned. A disordered cell structure is needed to adapt the standard cellular automata approach to urban studies. When constructing cell structures and states, features of geographic processes incorporate into transition rules and neighborhood relations. Integrating the cellular automata approach with geographic information system data allows the development of an urban model with constraints. Thus, urban planning scenarios can be formulated more easily (Sıpahıoglu & Çağdaş, 2022). The fact that many factors in the local, regional, and global context are influential in the development of cities reveals the importance of constraints in increasing model performance. The urban model will reveal generic patterns in a scenario without constraints and geographic data.

For this reason, it is vital to determine urban model scenarios and simulate the urban development model with the proper constraints. Constraints are necessary for accurate predictions rather than affecting the production of cellular automata models.

Constraints also allow the provisioning of systematic data to see the reflections of environmental and sustainable policies on urban growth. In this context, systematically taking data from the transformations of the selected urban area in the historical process is critical in adapting the restrictions. Such constraints are frequently encountered in studies such as environmental suitability, urban forms, development density, economic development, and sustainable development (Yeh et al., 2021) (Figure 4).

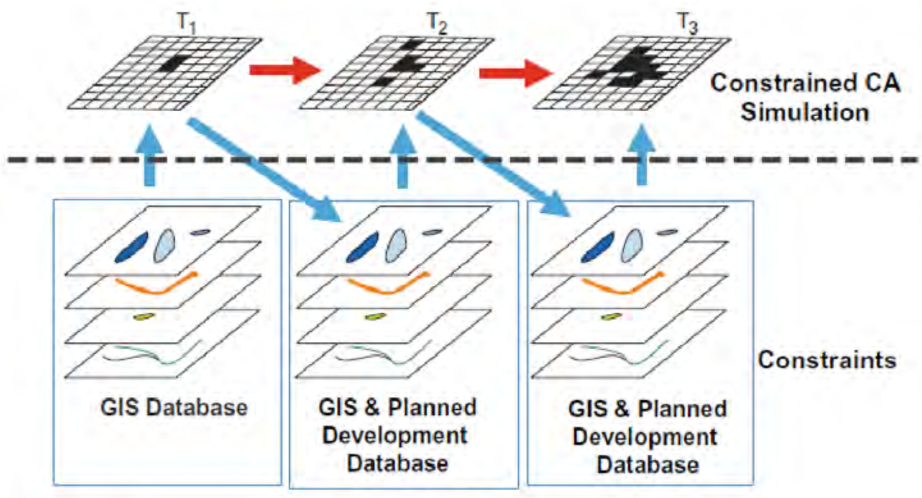

Figure 4. Constrained CA model (Yeh et al., 2021, p.870).

A large and classified data set is needed for urban development models to make accurate predictions within the scope of real-world simulation. The classified data set is vital in defining transition rules and neighborhood relations. In this context, remote sensing data are the most used data in urban development models. Filtering land uses on the earth's surface, and monitoring and measuring changes are possible with remote sensing data. For urban development models to make accurate predictions and to ensure model calibration, data on land uses in different periods are also needed. The remote sensing datasets may include road conditions, traffic networks, distance, natural features (slope and elevation), and physical factors. These data enable us to assess the suitability of land use changes for development. Datasets are classified into three categories: 1) Environmental factors, 2) Built factors, 3) Socio-economic factors. Environmental factors include topographic features. The slope plays a role as a determining factor in the determination of new settlements. Flat and gently sloping lands are simple to develop, while areas with less than 25% slope are considered suitable for vertical growth. Again, environmental factors include data on altitude, distance to coastal areas, green areas, docks, and open areas (Zhou et al., 2021).

Built factors represent the built environment that is independent of the natural environment. Circulation is an important concept. The prominent data are roads, land uses, infrastructure, and public spaces (Mustafa et al., 2018). Socio-economic factors include data such as population density and the number of residences (Poelmans & Van Rompaey, 2009). Using all these data sets contributes to the emergence of realistic simulation results (Chakraborty et al., 2022). Having many data types makes data quality a critical problem area. Calibrating the data is essential for the performance of the model. In this context, while classifying remote sensing data, categorization is provided by using the supervised classification method. Creating maps with different spatial resolutions and eliminating uncertainties is essential for comparative analysis. If there are errors and uncertainties in the data, the results produced by the urban model may be negatively affected and misleading. Creating a process analysis and flowchart is essential for urban models (Figure 5) (Yeh et al., 2021).

Defining and calibrating transition rules in the development of urban growth models is necessary to produce consistent results when generating past data and future forecasts. Since past time data and future predictions will be interpreted on the same rule set, it is essential to establish definitions on correct data sets (Clarke et al., 1997). In most cellular auto-based urban growth models, space reduction to square grids comes to the fore. This reduction ensures that the transition rules are applied iteratively to the spatial model. For this reason, the grid sizes used in the model and the remote sensing data must be the same. Cellular automata-based models developed to simulate urban growth are SLEUTH (Clarke et al., 1997), dynamic urban evolution model (DUEM) (Batty, 1997), multi-criteria assessment model (MCE) (Wu & Webster, 2000), multi-agent system (MAS) (Ligtenberg et al., 2001), Voronoi-based CA model (Shi & Pang, 2000), Markov-CA model (Vaz et al., 2014) (Tripathy & Kumar, 2019). The SLEUTH model, which is one of the oldest and best-known models, uses four essential data sets for the model; land use, slope, transportation, and restricted or protected areas (Clarke et al., 1997); MCE, which is a multi-criteria evaluation model, uses morpho dynamic layers, land use, slope, land carrying capacity, proximity to urban areas, and ecologically sensitive areas as a

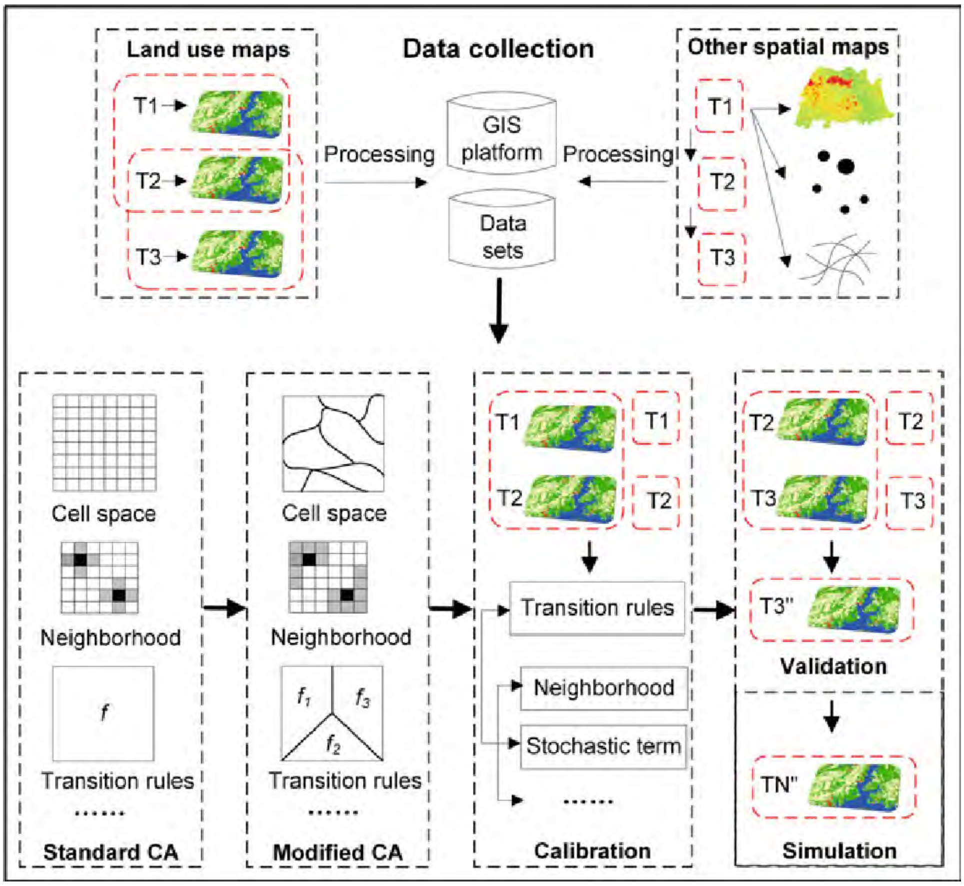

Figure 5. Flow chart of an Urban CA model (Yeh et al., 2021, p. 871).

data set (Bosque-Sendra, 2004). In the multi-factor system, data sets such as land use, population density, and transportation draw attention (Crooks et al., 2014). Since creating a model using a standard rule and data set is impossible, data sets must be prepared according to the determined scenario.

Although urban growth models have gained a versatile structure with technological developments, the selection and application of transition rules are at the center of research as an important problem area. The need for a specific design of transition rules and intensive computation to produce accurate results for urban growth models reveals the importance of developing models that are easy to calibrate and simultaneously apply urban growth's spatial and temporal dynamics. When examining the studies in the literature, it is seen that most models are developed according to individual preferences. For this reason, this study serves two purposes: 1) To accurately describe the function of neighborhood relations of data in an effective CA-based model to simulate urban growth, 2) To test the reliability of a model that considers the spatial and temporal dynamics of urban growth and conclude how it should be calibrated. While locally calibrating site-specific features is vital for spatial calibration, it is essential in terms of temporal calibration to give the model a structure that can adapt to the growth model depending on time. Within the scope of the study, the urban growth model will make this evaluation over two main data sets: Classified land use data for each cell for 1994, 2006, and 2018 and data from population density maps for 1994 and 2006.

Data Preparation

The data sets required for the study were created with remote sensing data as thematic layers. Land use and land cover layers were prepared using satellite data to understand urban growth dynamics for 1994, 2006, and 2018. Another critical data set apart from land use data is the preparation of population density maps. Apart from the land use and population density data, slope analysis, proximity to road networks, focal points, and the determination of the affected areas were prepared in raster layers.

GIS has become an essential tool that can be accessed globally and easily shared in terms of collecting, analyzing, visualizing spatial data, and acquiring new information. The widespread use of geographic information systems also enables spatial data to have increasingly detailed inputs. Thus, it is possible to collect appropriate data to solve complex problems. Although there is much alternative software for GIS that forms the data core of urban growth models, QGIS software, which is open source and free, was preferred within the scope of the study. Land use data was integrated into QGIS software with the Semi-Automatic Classification method. Environmental factors (slope, elevation) were obtained by filtering Shuttle Radar Topography Mission (SRTM) over USGS Earth Explorer satellite images. Data such as roads and focal points were integrated into QGIS software using the Open Street Map (OSM) database.

Land uses, which is the main focus of the study, are an essential source for reflecting built-up features. First, it is necessary to classify the remote sensing data to prepare the land use data of the region where the historical peninsula is located in Istanbul. The classification was prepared using the Semi-Automatic Classification (SCP) Plugin for QGIS. By entering the location information of the determined land, it is possible to download satellite images, process images and make raster calculations through the SCP plugin. While making the classification, four main categories were determined: 1) Built-up areas (such as residential areas, commercial areas, and public buildings), 2) Vegetation areas (such as parks and open public spaces), 3) Water-related areas, and 4) Other layers (Table 2) (Chakraborty et al., 2022; Yeh et al., 2021).

Table 2. Classification of Land Use Classes.

Built-up	• All artificial structures (residential areas, commercial areas, public areas, etc.)
Vegetation	• All green spaces within the urban area and its environments
Water Bodies	• All water bodies, including surface water bodies, lakes, reservoirs, ponds, rivers
Others	• All features, excluding built-up areas, vegetation, and water

After the categories and features were determined for the land use data, the maximum likelihood algorithm produced the classification. Sufficient training data is needed for the maximum likelihood algorithm to produce accurate results. It is possible to preview the training data and to check whether the data to be created is correct. Since the algorithm calculates the spectral distances of the remotely sensed data, training data was needed for each class. More training data is required for classes with close spectral distances (constructed areas and others) than for other classes. Classification is essential in the model as it determines the similarity ratio between the produced result and the actual data. Accuracy rates were determined according to classification. Similarity rates were calculated as 90.27% and 89.35% for 1994 and 2006, respectively. High similarity rates are essential for the reliability of the data.

Apart from land use data, population density is another critical data set for the urban growth model. The population density was prepared as separate data sets for 1994, 2006, and 2018 Population density data were obtained from the open-access Turkish Statistical Institute and World Population Hub database (WorldPop, & Bondarenko, Maksym, 2020). Spatial demographic data, research, and the open-access database made the population density data and population numbers of the desired years editable. The obtained density data were converted into raster layers to match the geometry of other layers required for the model.

Model

The definition of the urban growth model's transition rule, the model's calibration, and the evaluation of the results constitute the stages of the model discussed in the study (Figure 6).

The cellular automata model begins with defining the transitional rules that drive urban growth. These rules act as a function to constrain data such as land use and population density. Transition rules are defined through the neighborhood relation of cells. For this reason, transition rules have been defined over the 3x3 Moore neighborhood, which is observed to give more relevant results in urban studies (Sıpahıoglu & Çağdaş, 2022). By determining the neighborhood relations of the tested cells, the rules simulate their effects in the urban area.

Transition rules can be adapted according to the land uses and strategies for measuring the area where urban growth will be examined. In cellular auto-based urban models, the future state of a cell depends on three factors: 1) Initial state of the cell, 2) Initial states of neighboring cells, 3) Transition rules affecting urban growth. Determining the rules according to land use changes is essential to measure the CA model's reliability. In this context, land use of coastal areas, knowledge of areas to be protected, population density, and road use can be examples of transition rules. According to the transition rules, the transformation matrix of the classes was created (Table 3, Table 4).

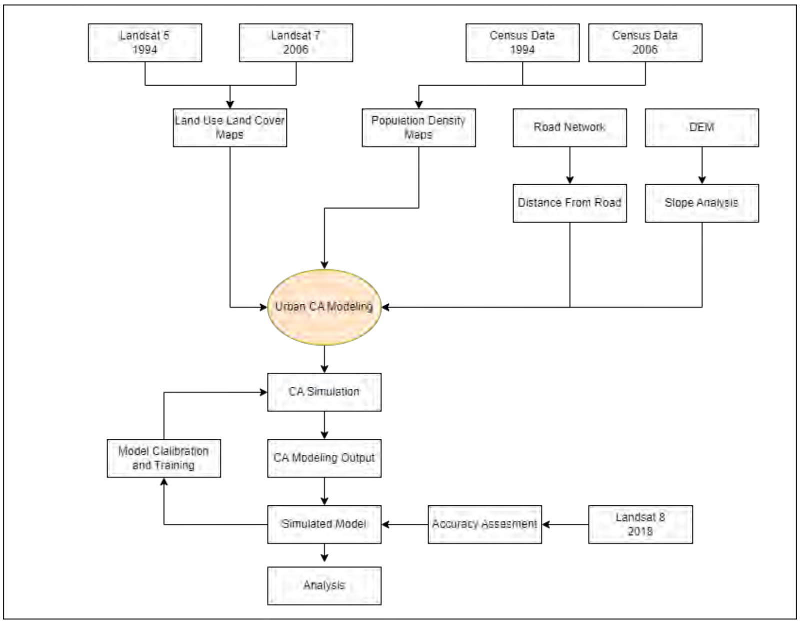

Figure 6. Flowchart of the model.

Table 3. Example of transition rules.

* *IF land class is built up (residential, commercial, road, etc.) THEN no change.*
* *IF land class is non-built up (vegetation or others), THEN it becomes built up* *if >> Population density is equal to or greater than the defined threshold* *AND neighboring built-up pixel count is equal to or greater than the defined threshold*
* *IF the land class is water, THEN no change.*

Table 4. Transformation matrix.

Class Type	**Built up**	**Vegetation**	**Water**	**Other**
Built up	Can transform	No change	No change	No change
Vegetation	Can transform	Can transform	No change	Can transform
Water	No change	No change	Can transform	No change
Other	Can transform	Can transform	No change	Can transform

After the urban growth model data were prepared, development simulations were produced using the independent software GeoSOS -Future Land Use Simulation tool. FLUS has an infrastructure that can integrate with cellular automata approaches. The results in the study area were compared to historical and today's data, and their relevance and validity were interpreted. GeoSOS-FLUS is an effective interface that calculates urban development by finding complex relationships between human and natural factors to make land use change simulations more convenient and efficient. FLUS can be used for various urban development scenarios as needed: 1) creation of built-up boundaries, 2) high-resolution simulation of land use change within the city, 3) environmental management and urban planning, 4) large-scale land use change and its impact on climate, 5) regional land suitability analysis, 6) early warning for loss of natural and agricultural land cover types, and 7) hotspot recognition for land use change. FLUS offers a suitable interaction environment for measuring and evaluating the effects of urban policies and projects, especially since the beginning of the 2000s.

FLUS integration includes some stages. Firstly, spatial variables and historical land use data were analyzed to predict the transition rules of land uses in the historical peninsula of Istanbul, which has a dense texture, in 1994 and 2006. A development scenario was produced using the analyzed land use data with population density, distance to roads, inaccessible areas, and topography data. Although FLUS offers an environment that allows for multiple scenarios, the primary use case was adhered to as the study aimed to measure the reliability of CA models in a dense and historical area. In the context of the baseline scenario, an urban simulation trial was conducted within the constraints specified for 2018. The year 2018 was chosen because it provides ease of analysis due to the completion of the activities and mega projects in the built environment on the coastline that affects the population and the presence of field studies belonging to the Istanbul Metropolitan Municipality. Since the urban simulation was conducted in 2018, the necessity of having land use data from the 2000s and before, when the activities in the built environment became more frequent, has emerged.

Results

The study aims to test the data from 1994 and 2006 in the CA model to create a simulation for 2018 and test the result's consistency and reliability. Table 5 shows the data on land use in 1994 and 2006.

Table 5. Transformation matrix.

Land Use (1994)	**Percentage %**	**Area [m]²**
Built up (Residential, commercial areas, etc.)	46.20%	108,424,800
Vegetation (Green areas, parks, etc.)	17.09%	40,093,200
Water (Sea)	29.25%	68,640,300
Other (Restricted Areas, Soil, etc.)	7.46%	17,504,100
Total	100.00%	234,662,400
Land Use (2006)	**Percentage %**	**Area [m]²**
Built up (Residential, commercial areas, etc.)	51.48%	120,806,100
Vegetation (Green areas, parks, etc.)	14.99%	35,177,400
Water (Sea)	29.25%	68,640,300
Other (Restricted Areas, Soil, etc.)	4.28%	10,038,600
Total	100.00%	234,662,400

When we look at the change from 1994 to 2006, there is an increase in both area and percentage in the built environment. It is seen that the transformations in the defined transition rules have taken place. The fact that the road data stayed the same and the distances to the roads were fixed ensured that the change was not too much. Interpreting the changes in green areas is more understandable, as the built-up areas currently cover most of them in percentage and numerical terms. It is observed that there is a decrease in the area and percentage of green areas, and accordingly, other data variables and some of the green areas have turned into settled structures (Figure 7 & Figure 8).

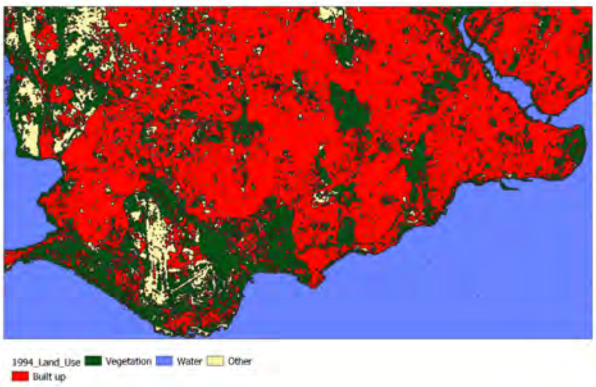

Figure 7. Land use of 1994

With the spatial changes and transition rules analyzed according to the data in 1994 and 2006, the 2018 simulation was made in the second stage. The purpose of the simulation was determined to test the adaptability of CA models as decision support systems in dense urban areas and to measure their reliability. The 2018 simulation produced a result that matched the data and changes in 1994 and 2006 (Table 6). Although the built environment has increased in the area, it has yet to show a significant percentage increase. Transition rules enabled transformations primarily between green areas and elements in the other class.

After the calculations, the analysis showed that the simulation changed the coastline and green area very little according to the

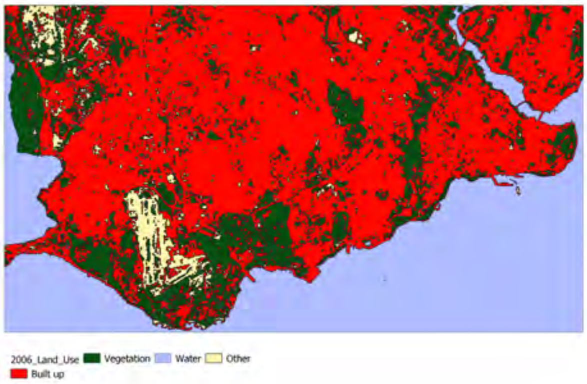

Figure 8. Land use 2006.

Table 6. Land use percentages and area (2018).

Land Use (2018)	Percentage %	Area [m]²
Built up (Residential, commercial areas, etc.)	51.77%	121,475,700
Vegetation (Green areas, parks, etc.)	16.00%	37,537,300
Water (Sea)	29.25%	68,640,300
Other (Restricted Areas, Soil, etc.)	2.99%	7,009,100
Total	100.00%	234,662,400

transition rule. However, the transformation caused by the projects made on the coastline of the historical peninsula as a result of the changing urban policies, especially in the 2000s, provided inconsistency for the model that made the 2018 projection by learning from the 1994 and 2006 data (Figure 8) (Figure 9).

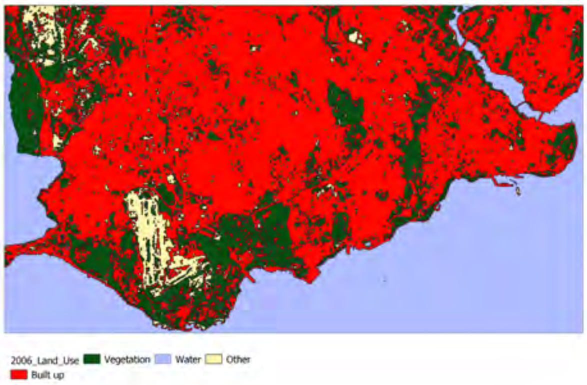

Figure 9. Land use 2006.

As a result of urban policies such as mega-projects and filling areas on the coastline, the decisions that changed the urban texture dramatically did not comply with the transition rules of the model, causing the calculations to be inconsistent. In this sense, although CA models have the power to make accurate urban development predictions with correctly defined rules and correct data sets, the unpredictable elements in urban dynamics have revealed that we need to produce development models with different and multi-layered scenarios. CA models in urban development are a tool with high potential as a decision support system.

Figure 10. 2006-2018 Land Use Changes.

Discussion and Future Work

Urban CA models try to solve complex problems with a simple system structure. Although the simple structure increases the rapid development of the models and the ability of the models to solve complex problems, constraints arise in real life where urban dynamics are concerned. Extensive modifications are needed to remove the restrictions. On the other hand, since CA models have a flexible framework, they have the potential to be adapted to the desired environment. However, at this point, when dealing with a real problem like urban development, the problem of standardization arises. Flexibility can complicate the situation without a standard approach to the rules. In this respect, a CA model for urban development should be capable of making standard definitions in a simple and flexible framework for real-case scenarios. This study tested the suitability and adaptability of CA models in an area with a dense urban fabric. Although the CA algorithm can produce results suitable for the desired situation, unpredictable urban dynamics can prevent its practical use. They can be used as an interactive urban design tool when all stakeholders active in urban policies are part of the decision-making process. In this respect, urban CA models are descriptive, complementary, and capable tools as decision support systems. This study in the historical peninsula of Istanbul serves as a framework for future studies. Expanding the dataset, increasing the data range, and increasing heuristic learning are necessary to obtain more consistent results and make the model adaptable to different scenarios. Within the scope of the study, an evaluation was made of the local urban texture in 2018 using data from 1994 and 2006. To use CA as a decision support system in the local environment, the need to develop local-specific scenarios and analyses based on these scenarios has emerged. At the same time, for CA to play a more active role in urban development processes, it is necessary to integrate different periods into local scenarios and models. Conducting future simulations on specific scenarios is essential for a clearer understanding of the suitability of CA in a local fabric and the flexibility and adaptability of urban development models.

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RESEARCH ARTICLE

Information and Communications Technology (ICT) Impact on Architects: Disruption and Hybridization Process

Emre İŞLEK[1], Mehmet Emin ŞALGAMCIOĞLU[2]

[1]PhD Candidate, Istanbul Technical University, Graduate School, Architectural Design PhD Programme, Istanbul, Türkiye
[2]Assoc. Prof. Dr., Istanbul Technical University, Faculty of Architecture, Department of Architecture, Istanbul, Türkiye

ABSTRACT
Information and Communications Technology (ICT) impact and adaptation issues to emerging technologies have been widely researched in many sectors, as information has become vital to any business activity. Architectural practice, as an information-centric profession, is directly affected by the transformation and development of ICT. However, research on the impact of ICT on architects and architectural offices in Turkey has been limited. This study uses Grounded Theory methodology to study six cases with different ICT adaptation levels and workflows. The case study shows that architects can hybridize with new technology at the very beginning of the practice. However, increasing complexity due to the continuous transformation of ICT disrupts the habitat of hybrid architects. The disruption leads to a new hybridization phase, a complicated process for an architect who has to change the mindset of an earlier period.

Keywords: Information and Communication Technology (ICT), Architecture, Grounded Theory, Hybridization, Disruption

Introduction

Information and communication technology (ICT) is indispensable in modern life. In today's world, *acquiring, storing, retrieving, transferring, and disseminating information is almost impossible without using computers, telecommunications, micro-electronics, and their applications*"[1]. However, ICT, which is in use and well adopted by the sectors, continues to transform in parallel with new developments. The constant transformation of ICT has an effect on architecture, which is an information-centric practice (Kalay, 2006), today and had historically.

The first research on ICT developments affected architectural design in the 1960s, when information technologies began to be used (Pena, 1969; Alexander, 1970; Negroponte, 1975; Cross, 1977; Mitchell, 1977). The emergence of information technology has led to a radical change in the media of the communication process and the distribution, storage, and verification of information. Researchers have described the period starting from the mid-20th century[2] after the industrial age as a new age with different names: information age, digital age, or computer age in various resources (Castells, 1996); Lannana and Uy, 2003; Webster,2001). While the ICT developments began in the mid-20th century, the widespread use of new technologies took time. The diffusion of ICT to all sectors has increased, especially since the 1980s, with the general use of personal computers. ICTs became ubiquitous artifacts a decade later, in the 1990s (Mansell & Steinmuller, 2000). Freeman and Soete (1994) describe this diffusion process as the pervasive power of ICT; "*The pervasiveness of ICTs is not just a question of a few products or industries but of a technology which affects every industry and every service, their interrelationships and indeed the whole way of life of industrial societies*."

In the 1990s, with its pervasive power, ICT diffused more into architectural design. Architects began to question these transformations and attempted to find their positions. For example, Eisenman (1992) defined this situation as a paradigm shift from mechanical to electronic and asked, "*How have these developments affected architecture?*"

Nearly 40 years have passed since Eisenman asked about the effects of ICT on architecture. This question is still relevant, as developments in ICT continue to transform architectural practices. Within the last 40 years, architects learned to manipulate the

[1] https://www.lisedunetwork.com/ict-concepts-and-meaning-definition/
[2] Alberts at al (1997), The Information Age: An Anthology on its Impact and Consequences can be checked for a brief history of ICT developments lived in the information age and before.

Corresponding Author: Emre İŞLEK **E-mail:** emreislek@itu.edu.tr

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design in real time with visual objects directly, used CAD technologies to reproduce the documents, and became familiar with the spline tool with the help of digital design (Carpo, 1992). According to McCullough (2006), "Design computing which is no longer ’just a tool’ (in the apologetic sense of not influencing one’s intentions), rapidly matured as a medium in which bias, appreciation, expression, and new genres were inevitable."

In the 2000s, a new shift started from CAD to BIM models. Jernigan describes BIM (Building Information Modelling) as; "*The management of information and the complex relationships between the social and technical resources that represent the complexity, collaboration, and interrelationships of today’s organizations and environment*" (F., Jernigan, 2007). 2D CAD drawings and analog actions cannot handle fundamental concepts such as *complexity, collaborations, and interrelationships*. Consequently, the AEC sector started to use building information models (BIM) to integrate the increasing amount of information produced during the project.

Oxman (2006) marked early CAD models as an attempt to depart from paper-based media (Oxman, 2006); from her point of view, we can characterize BIM tools as an attempt to depart from CAD models. However, in the first years of BIM, the construction industry was not yet mature enough to understand the potential of computer-aided design as a decisional tool to support the entire construction process (Pavan et al., 2020). As a result, the majority of the actors in the building industry use BIM in a reductive manner (Kalay, 2006).

Nevertheless, the construction industry, one of the lowest-digitized sectors (Manyika, 2018), started to change. ICT developments had a positive impact on it. The construction industry has begun using computational tools, production technologies, and advanced digital applications more efficiently. This development has also affected research in this field. Lu et al. (2015), researching 635 ICT-related articles within the journals of AEC, finds out that (Figure 1) among the six types of various users, contractors, and subcontractors are the leading adopters of ICT. According to researchers, the increasing number of contractor-oriented articles results from the construction process, which demands massive and accurate information to make decisions and improve efficiency and performance.

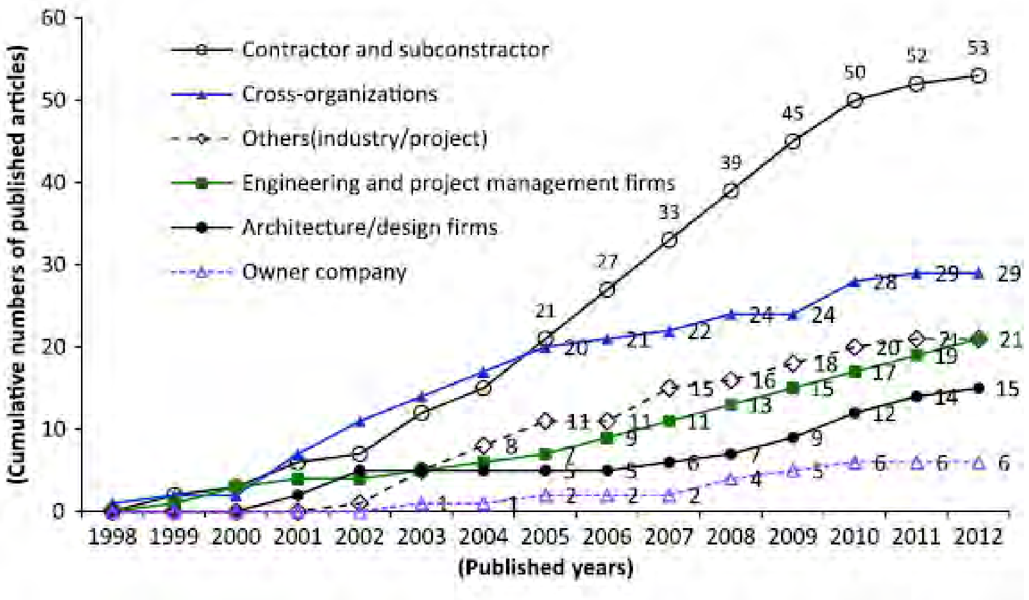

Figure 1. The cumulative number of ICT articles in the layer of organization of 12 total journals by publication years during 1998-2012 (Lu et al., 2015)

Lu et al. (2015) show that ironically, ICT adoption and the demand for research are less in architecture and design firms, unlike contractors. However, engineers demand more information than architects do for ICT adoption. Surprisingly, ICT’s impact on architects and the profession has yet to receive much attention in the research field. Studies on practitioner reactions to developing technologies are rare.

While ICT transforms the habitat that architects practice, both in the research and practice fields, architects’ reactions to this transformation can be defined as an externalizing process. Architects focus on their design objects, while new actors and consultants have arisen to cope with the increasing complexity of construction processes. The design process is changing, as there are new IT applications and construction techniques which architects are unfamiliar with. This change leads to the following research question.

- What are the possible outcomes of ICT that has an impact on architectural design process and how do architects react to technological developments?

Research Methodology

Information on the impact of ICT on Turkey's architectural figures and design processes is limited. As technology is developing at an increasing speed, the new culture of the architectural design field is reshaping continuously. The researcher is interested in the architect's subjective experience in his new culture, transforming it with the impact of ICT. To capture these objectives, researchers designed hypothesis-generating qualitative research using the grounded theory methodology. First, the research questions were shaped, and semi-structured interviews were conducted with six offices with different technology levels, structures, and working habits. In the analysis stage, data were examined in detail using the techniques described by Strauss and Corbin (1988).

Grounded theory is a general methodology with systematic guidelines for gathering and analyzing data to generate middle-range theory (Charmaz & Belgrave, 2007). Researchers prefer to use it mainly to reveal the reasons that affect the emergence of a phenomenon that is poorly understood and incomprehensible. The analytic process consists of coding data; developing, checking, and integrating theoretical categories; and writing analytic narratives throughout the inquiry. There are two main parts of the grounded theory: open and axial coding.

Glaser and Strauss (1967) propose that researchers collect and analyze data simultaneously. In grounded theory, from the beginning of the research process, the researcher codes the data, compares the data and codes, and identifies analytic leads and tentative categories to develop through further data collection (Charmaz & Belgrave, 2007).

In this study, audio data records were first decoded into texts. Subsequently, researchers explored recurrent patterns and variations to define codes in the open-coding phase. These codes were used to construct distinct categories using axial coding. Categories were linked in the selective coding phase, leading to research themes. (Figure 2)

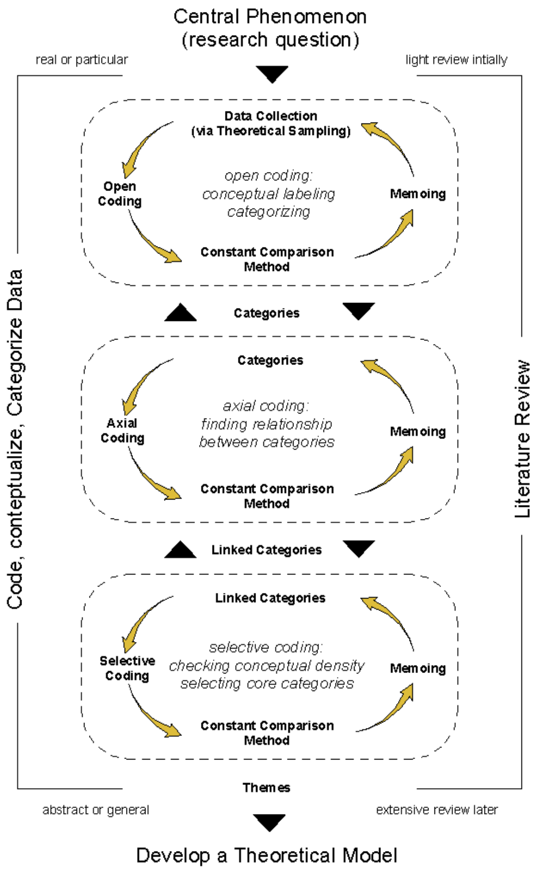

Figure 2. The research Model of the Case Study was adapted from Hoda et al. (2012).

Corbin and Strauss (1988) mentioned paradigm-based coding as an analytical tool to help analysts carry out axial coding or coding around a category. It consists of 3 main features: conditions, actions, and consequences. However, during the coding phase, the researcher realized that capturing actions-interactions provided limited information for creating the categories' central ideas.

Participants mainly mentioned their values or attributes to the conditions and did not want to provide much detail about their actions. Therefore, to capture any meaning that a sentence can hide, we used a 5-labeled coding process in the open coding phase: open coding, process coding, descriptive coding, values and attribute coding, and emotional coding.

Open coding is the first impression of what the participant mentions and how he or she describes causal conditions. Something happens, and the participants must mention it or talk about a situation, trying to explain why the this phenomenon or paradigm change happened. Process coding describes the actions or interactions of a participant. Participants developed these actions as a strategy because of this phenomenon. Descriptive coding labels the object of a sentence as a participant. Codes explaining the values and attributes were shaped as a vital header because the participants mostly talked about their beliefs, values, and attributes. Instead of describing their exact process in architectural design, they mostly share their opinions about how it should be, how an architect should behave, or their difference from others who work as a cogwheel of the system. The emotional coding label explains whether the participant shares emotions such as happiness or fear.

After the first coding phase, axial coding was performed to link the categories and subcategories into a broader framework. Following axial coding, the selective coding phase was initiated. In the selective coding phase, categories are integrated and refined into themes. For example, it has emerged from axial coding that personal values, the mindset of architects, and their concerns are shaped through the transformation of ICT.

Participant Profiles

The six architects who participated in this case study lived in Istanbul. Two architects run the architectural firm independently: four architects have partners and three have partners with their spouses. Members of the study group were born between the years 1964-1980. This range can provide clues about whether age plays a role in the impact of ICT on architects, as the participants faced a technological revolution at different ages and positions.

Five of the six participants graduated from Istanbul Technical University (ITU). Only one participant was from Yıldız Technical University. Five of the six participants had a master's degree, three had master's degrees taken abroad, and two were from ITU. Unlike other participants, one of the participants was a Professor at ITU while simultaneously working as a professional architect. Two participants had experience of working abroad.

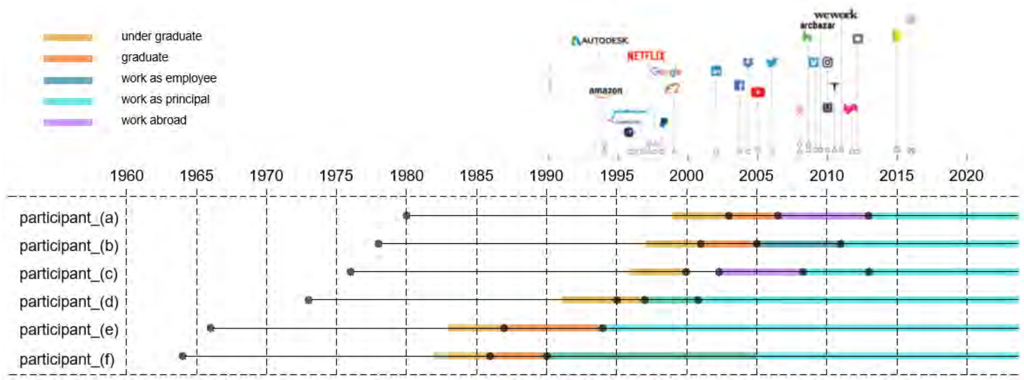

Figure 3. Participant profiles: Education and work experience, combined with Bartling, R.J. (2019)

RESULTS

The data analysis from open coding to categories reveals the emergence of three themes: the effect of the increasing complexity of the issues not related to the architectural design process, the traces of disruption in the personal sphere of the architect, and the hybridization process with the emerging technologies to cope with the complexity,

The effect of the increasing complexity of issues is unrelated to the architectural design process.

The architects mentioned various issues not related to the professional field of architecture, but that affected their design process. These issues are grouped under increasing complexity, mostly referred to as new conditions or challenges that they have not faced before. Architects describe increased complexity in three subcategories: increasing information exchange, increasing uncertainty, and decreasing project time and budget. In the interviews, architects linked increasing complexity to the increasing scale and detail level of new buildings (Figure 4).

The increasing amount of information exchange:

The participants stated that project actors and new specialties have increased in recent decades. Architects link this increase to increasing scale and detail levels, and to contemporary issues emerging in the world, such as the climate crisis. In addition, expertise has been divided into different areas, especially in engineering, so there is a natural increase in the number of actors involved. Some participants described this division as a breakthrough for the engineers. As a result, architects must coordinate with more consultants than before. The communication process extends as they talk to all actors in the project and listen to all their comments. The increase in communication creates a greater information load for architects who manage coordination. However, for some architects, managing this information process can make the work enjoyable for other actors in the project. One architect also highlighted that information could become junk if it is not managed. Some architects use digital tools, such as BimDocs by Autodesk, to manage information flow. According to Participant_(f), the increase in the number of consultants is a new fact; however, today, what makes it different from the past is the accurate management of information with digital tools. It can be said that coping with this new workload becomes uneasy without digital tools due to the new conditions of the complex environment.

Increasing Uncertainty

Increasing uncertainty has emerged as a phenomenon affecting the progress of the architectural design process and the way of managing business and decisions for the future. The most mentioned sub-category of this phenomenon is the client's uncertainty, which directly impacts the management of the design process. According to architects, clients were uncertain and could not decide from the beginning of the project. As a result, major changes occur very late in the project. To cope with this uncertainty, architects have attempted to extend the time of the preliminary project phase as a solution. Another solution is to keep the client in the process from the beginning. However, even if architects settle the building program with the client, this process brings the client criticism of the program.

Similarly, long waiting and evaluation times with long decision processes can be read as client uncertainty. In contrast to the other participants, one architect defined uncertainty as a typical situation in this era and emphasized that he designed it accordingly. Another architect mentioned that uncertainty is a concept that creates space for people to stay in the gray zone, where many actors feel safe not to make decisions.

Another sub-category of increasing uncertainty has been shaped as 'the lack of an appropriate budget.' This subcategory occurred at different times during the interviews as a disincentive factor. A crisis occurs every ten years, which makes it impossible to invest in the firm without financial precision. The budget problem is defined as not only limited to the firm's future, but also the labor working for the office. Architects compare their budgets with Western countries and describe themselves as having low project budgets, which is a problem that prevents working with necessary consultants. A low budget is also defined as a problem for engineers, as it does not allow them to invest in software or training to collaborate with the architect's team. Another point of view highlighted by one architect is the client's budget, as he believes that clients are working with him since he can protect their budgets in this uncertain era.

While five architects used negative statements for the concept of uncertainty, one architect used a different approach. According to him, digitization can be defined as both uncertainty and flexibility. Before this era, the time, budget, and project targets were stable, unlike today. The architect mentioned that he did not see a low budget as a problem in his practice. This is probably due to the economic structure of his office. His work model differs from those of other offices. He calls a sponsored design service, making a long-term contract with a construction firm and maintaining a constant payment for his services.

Decreasing Time and Time Management

The increase in the scale of buildings increases the information level and communication workload of architects, both with the client and within the architectural design process, resulting in a time-limitation situation. Architects are trying to spend more time thinking about the process, but cannot, as they experience time pressure. The phrases used as a negative expression are "compete against time," "time pressure," "spare time," and "isolate me to use time better." The increasing time pressure on architects has been defined as a specific property of today since the 1990s. However, while five architects discussed the time pressure on them or their design process, one architect did not mention this issue. This is probably due to his working methods and process management. From this point of view, another architect added that to manage time better, they were refusing projects impossible to finish in a logical time.

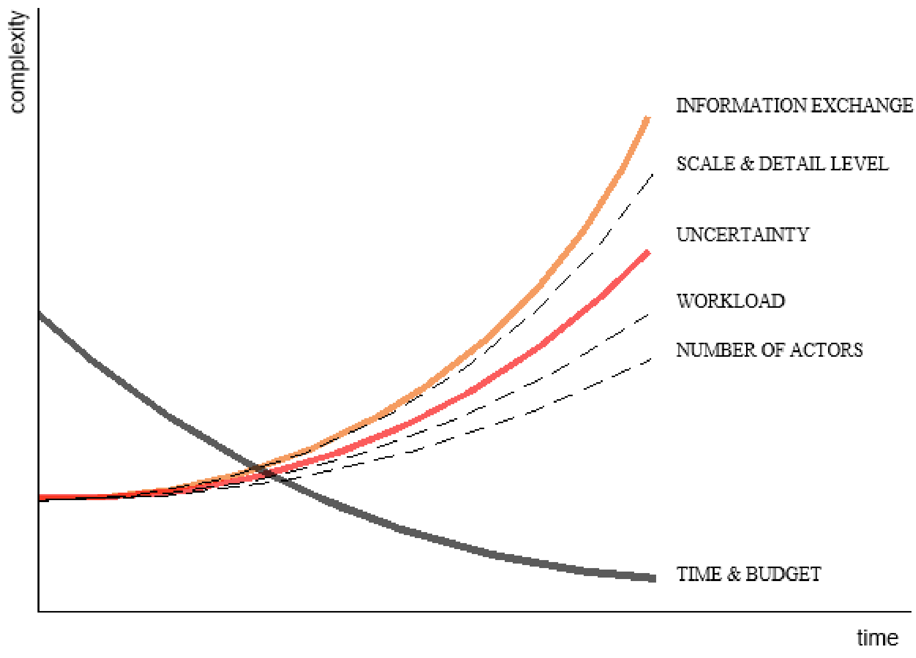

Figure 4. Architects' perceptions of complexity in project workflow.

Traces of disruption in architects' personal spheres

Absorption of digital technologies without changing the analog mindset

Data analysis showed the 'mindset' as a central concept. The participants discussed analog and digital mindsets. Architects highlighted that they did not believe that the mindset of architects changed in parallel with the developments in ICT (Figure 5). While architects use tools with the mindset of the analog period, they are also reluctant to change the tools they use or how they use them because it is difficult to change their comfort zone.

The comfort zone emerged as a sub-category that prevented changes in working processes. Employees and firm owners do not want to change their comfort zones. It can be understood that the way architects are accustomed to is the most feasible way to complete their issues. The comfort zone is the space in which they act the best. This comfort zone is so strict that it allows employees to resign. For example, one participant's motivation to transform the office was stuck in the employees' comfort zones, which led to their loss. Another participant mentioned that it was difficult to change the habits of the architects. They cannot change employees' comfort zones even if they provide enough time and resources. This situation can be explained by an analog mindset situation. Even though tools or resources have changed, architects cannot quickly digitalize or adapt to a digital mindset. Some architects defined themselves as architects of the analog period, as an extension of the twentieth century. They described the education system of the twentieth century. Architects continue to use the methods they learn. Another participant described himself and his generation as having a linear mindset. However, when the same participant mentioned his office, unlike himself, he highlighted that their minds work digitally.

Working in a digitally configured office structure allows analog-minded architects to cope with the digital complexities. One participant described himself and his generation as having a mindset that had to be changed to catch the transformation or communicate with the new generation. According to him, architects must also change their mindsets to catch up with clients.

The significant separation of the 'world of thought' & 'world of operation':

Participants mostly separated the idea world from the operational world. As mentioned, ideas are often shaped through an architect's mind; the tools are part of the operational world that helps visualize or develop this idea into construction documents.

One participant highlighted that the 'idea world' of the architect is independent of the tools, giving the example of the architects of analog periods who were able to construct without digitized tools. As computers' idea generation process is also dependent upon humans, ICT can only be an assistant for the idea to rise, unlike paper or pen. They also believe that BIM or other software is not directly linked to the production of architectural thought. Participant_(b) stated that he could produce answers independently and did not need any tools to help him find these answers. He also emphasized that their problem was not about creating ideas or

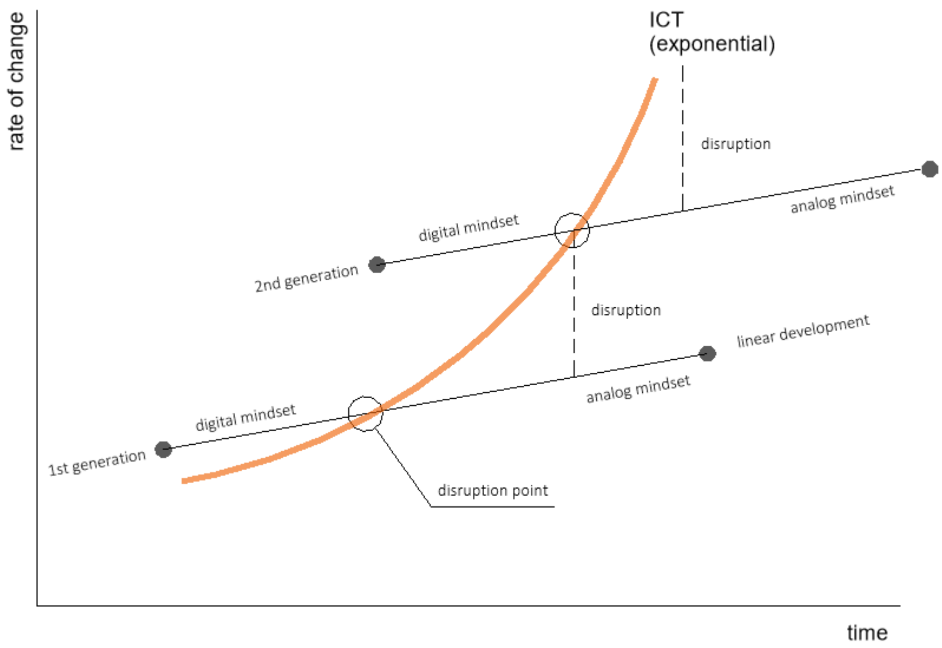

Figure 5. Disruption of architects through exponential development of ICT

designing itself. It can be said that until he sees an issue, he will not use any tools to assist him. 'Sense of space' and 'idea of the building' are more important concepts for the architects than the model produced to view the idea.

The separation of the 'idea world' is essential for defining the architect himself. Participant_(f) clearly stated the importance of asking questions about architecture rather than using tools.

Unlike other participants, Participant_(d) mentioned that the main idea is not shaped within the brain of the leading architect, but is a common idea of the office. According to him, he was using the analysis of the tools, but the idea was coming through the architect anyhow. However, one participant who used BIM tools more than the other participants stated the opposite. He mentioned that the design is not a separate process. Moreover, he did not see computers as simple tools, but saw himself as a tool for computers.

Even if the 'idea world' is separated from the tools used by architects, a connection is highlighted by the participants. It has been stated that the interpretation of ideas in digital space changes with the transformation of tools. Computer-aided numerical data are also involved, inevitably causing architects to interpret the information in the main idea. Architects emphasized that the operational world is separate from the thought world, but the operational world's tools support the thought world. With these new tools, architects can test their choices based on intuition.

Architects are attempting to relocate themselves to the digital world:

The data analysis shows that architects try to change their working methods and thinking patterns according to the new digitized workflows to adapt to the new digital mindset. Digital mindsets are open, transparent, shared, and easily accessible (Show et al., 2022). However, in this adoption process, architects raise negative projections for the future, mentioning concerns about the new generation with new abilities and tools.

A sub-category that emerged under this category was fear of losing control. Architects at the center of information flow are essential in the design process. The change in tools or actors in the design process can damage this central position. Participant_(b) mentioned that he was using the software that he knew because he wanted to control the entire process through the tools he used.

Participant_(e) knows that the transformation is ongoing and attempts to understand the changes. However, he is afraid of living a break with the new generation. Like participant_(e), participant_(c) is also afraid of a break with the new generation, so he tries to try new technologies and catch up with the digitization process. Participant_(d) also tries to catch up with new technologies, such as participant_(c). He mentioned his fear of new technologies being able to do what he could do as an architect. Nevertheless, he is not concerned, as he learned that there is still time. Participant_(a) stated an issue similar to that of participant_(d). According to her, software can quickly publish an application project. Moreover, she believes that this is an issue that architects fear.

Collaboration with the new generation is another action that architects have taken to locate themselves in the digital era. Participant_(d) described himself as a design manager who tried to collaborate with his team. However, it should be noted that he could not use the software used by the design team. This handicap could be a reason for Participant_(d) to collaborate with his design team to survive in the digital workflow.

Unlike participant_(d), participant_(b) used the same software as the design team. According to Participant _(b), lead architects should be able to use the same software; otherwise, there would be an instrumental break. However, the software used in the office is not a contemporary BIM or parametric tool. In the case of any need to change the tools used, participant_(b) can experience a disruption in the work process. He did not mention catching up with new technologies or software.

Hybridization with emerging technologies to cope with complexity.

As seen in the previous section, ICT's transformation of daily life and sectors impacted the architectural design process. Architects have been working to hybridize digital tools to cope with issues that do not occur within the profession. Some participants relied on available technologies that had been internalized before. Others collaborate with the new generation, which can use emerging technologies.

The hybridization process has two main subcategories: hybridization with information technologies and hybridization with communication technologies. As information technology architects use changes rapidly, hybridization with information technologies can be defined as an issue that is more familiar to architects. However, hybridization with communication technologies can be relatively new because of the wide usage of the Internet and social media over the last few decades.

Hybridization with information technologies:

The interviews showed that software selection in a project is mainly related to time management. Participants highlighted that they mostly chose the software according to the time they could spend on the project. The software can be a modeling tool or a project management tool. These tools are seen as a possibility of gaining more time with them. They mentioned that if they have limited time, they can change working methods, such as using a sketch-up model instead of making a physical model to see around.

Interestingly, architects quickly return to their habits and methods they are accustomed to in the case of time limitations. Unfortunately, the time allocated to the project phase is limited in Turkey. A limited time can be seen as limiting the development of architectural design offices. However, Participant_(f) had a different perspective. According to him, even if architects are given the necessary time, they cannot change their working habits.

This situation was coded in the previous theme as a mindset change and reluctance to change the comfort zone. ICT disrupts architects' comfort zones. For example, participant_(e) prefers not to use new technologies in his workflow because he thinks they are slowing him down. Nevertheless, he was sure that digital technologies did not change his way of thinking, but changed the time he spent. Like Participant_(e), Participant _(f) noted that generative design solutions to generate new geometries could be an option for obtaining short-term solutions.

Participant_(a) also linked the methods used in the project and was directly related to the time issue. The variations created within the software helped her manage the time better. However, creating more variations and looking at other options are linked to the architect's time.

The creation of variations is essential for architects. However, variation-making is a time-consuming process. The variations created within the software help architects better manage time. It can be said that before digitalization, architects needed to limit the alternatives they could produce because of real-life limits. However, architects believe that digital tools remove these limits and allow architects to recapture the other options they have left out.

Another participant emphasized that the usefulness of digital technologies was the ability to simulate the project. The study participants saw the possibility of seeing a digital model representing the real as an important feature.

Participant_(b) highlighted that the simulations are valuable for seeing the design as it is in real life, which is vital for capturing the atmosphere of the building. Architects use digital technologies to capture what is essential to the design process. For example, participant_(b) found that the sense of space is a critical value in architectural design. Thus, he was looking for digital tools to help capture the feeling of space. Unlike participant_(b), participant_(c) determines the calculations of the 3D model that are important for the design process. So, what he understands from simulating the building is not the architectural elements, but the calculable value of the model.

The expectations from the simulation also affected the programs used for the simulation. Participant_(c) only used Revit for creating 3D models; they are all BIM models that include parametric information buried in objects. However, participants (b) and (e) used Lumion as a simulation tool. It should be noted that Lumion, a simultaneous render software, unlike BIM tools, only provides visual data with the textures of the modeled design.

According to the participant, participant_(f) simulations were performed to determine alternative solutions and possibilities. Nevertheless, Participant_(d) stated that simulations should be performed with the manufacturers' elements as they will be produced. In this manner, the model can represent any problems that may occur during construction.

Architects find digital tools useful for capturing the architect's 'idea world' into a digital model that other parties can see. This digital model helps them interact with people and discuss ideas. Participant_(c) mentioned that with digital media, information about the project could be taken out of the architects' minds, and it can be reachable by anyone in the project.

Digital tools also help architects overcome other limitations such as distance. While Participant _(e) highlighted that technology should not dominate the design field, he appreciated the value of sharing the project with clients via digital tools. Participant_(f) considers platforms such as BIMdocs to be valuable in protecting the information produced during the project phases. Participant_(a) also used BIMdocs in her worldwide project to share her documentation.

Participant_(a) highlighted another issue that digital tools are capable of. According to her, architects can protect their designs using digital world tools. Because there is a simulated model of the project, changes in construction performed by constructors can be limited. With the 2D projection of the design, it is a well-known issue that most of the information is divided into parts, and most of the time, the constructors cannot construct as defined in the project.

While all the participants appreciated the various digital tools they used, they also highlighted the limitations of the new tools.

When discussing generative design, participant_(d) mentioned that adaptation to new technologies requires time. He provides an example of their adaptation to BIM platforms. Participant_(e) highlighted that catching up with new technologies requires time. Nevertheless, he also mentioned that when a break occurs, it becomes more difficult to communicate with others as they will be talking in another language.

Another topic regarding the limitations of new tools is the cost of new technology. As software is sold in international currencies, in the context of Turkey, it becomes unaffordable to buy that software. Participant_(e) complained that while they wanted to build a digital environment, they could not get the budget for this extra effort. Participant_(d) describes buying new software as "burying the money into it." Investment in new software can be considered necessary if the current tool can be used in the same situation. Participant_(f) described this situation as a question because not everyone can access it. Consequently, new digital tools have become pervasive. Participant_(a) addressed the cost of new technologies as a limitation. She added that she could not find engineers to work in BIM since engineers could not invest in new software because of the high cost. According to Participant_(f), the exact reason for architects and engineers not working in the BIM-based software can be counted. Participant_(e) was aware of the shift to new software. However, he was not ready to pay the cost of the new hardware and software required.

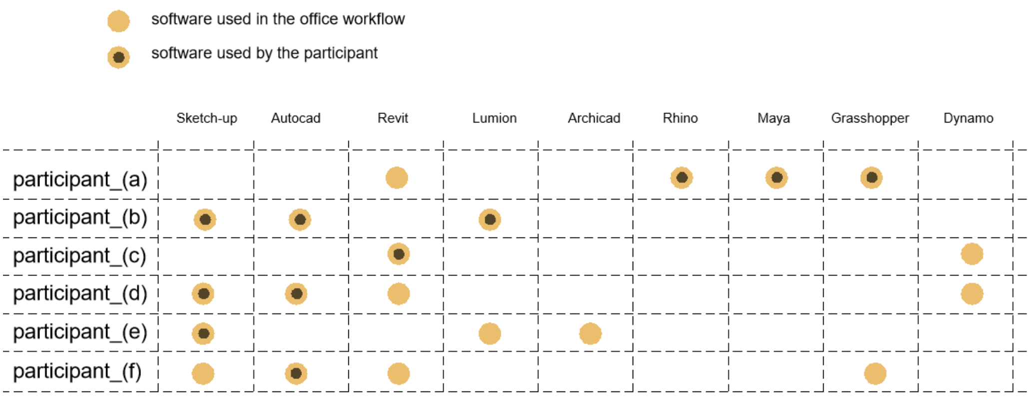

Figure 6. Software usage of participants' office structures.

Hybridization with the communication technologies:

During the interviews, participant_(f) stated that he saw the transformation of communication technologies as affecting architecture more than the transformation of tools related to architecture. He indicated that communication technologies, such as Pinterest are changing how architects reach architectural knowledge, which is reduced to visual data, independent of its context.

There is no consensus regarding the use of social media. While some participants did not approve of social media use as a world of images without any context, some saw the images as similar to the pictures in magazine clients who were accustomed to. Participant_(d) considered Pinterest a site forbidden in the architectural studio. Unlike participant_(d), participant_(b) mentioned the Pinterest architecture as good. Similarly, during his narration on social media, Participant _(e) highlighted the importance of Pinterest for him, replacing the magazines he buys in his office.

For participant_(a), using social media such as Pinterest is a must-be, but she added that she is not searching to feed herself with the images, but to know what is being built in other parts of the world. This approach can be coded as maintaining communication with others through social media. Participant_(b) highlighted that their last project could only be conducted with social media and communication through it. He describes these online works as encounters.

Whether the participants found it useful or not, it was seen in the interviews that communication through social media and other media is increasing. This increase creates constant communication with the client, other parties, and architect. Participant_(a) highlighted that digital tools enable the brain to communicate better than before. Participant_(b) added that increased communication created a more demanding client. This more demanding client can also relate to architects' increasing time pressure and workload. However, participant_(b) seemed to be used in this communication, and he added that they had to keep it constant.

DISCUSSION

By exploring the impact of ICT on different profiles of architectural offices in Turkey, this study aims to understand the transformations occurring within the architectural design process and in the personal sphere of architects.

The study's findings showed that the rapid development of ICTs disrupts architects' architectural design processes and personal spheres. To overcome this disruption, architects have attempted to hybridize with emerging technologies. The hybridization process was found to be linked to the disruption level of the habits and mindset of the architect.

The two concepts emerging from the data analysis, "Disruption of the architect" and "Hybridization of the architect," will be discussed in this section.

Disruption of the architect

According to Floridi L. (2015), the world is grasped by the human mind through concepts. Concepts provide an understanding of surrounding realities and a means to apprehend them. Floridi (2015) highlighted that the current conceptual toolbox of humans is not suitable for addressing new ICT-related challenges. Consequently, negative projections will arise in the future. It can be seen from the case study that the conceptual toolbox of architects to understand the world and act in the architectural design process does not address new challenges. This situation leads to disruption of architects' personal spheres. As new methods, technologies, and procedures emerge, architects are trying to relocate themselves to the digital world to overcome this disruption.

In general terms, 'disruption' has multiple meanings, ranging from prevention, disturbance, disorder, disassembly, to interruption[3]. In this study, the disruption concept is used for technological transformation that affects the traditional architectural design process and prevents it from continuing as expected.

Disruption occurs when technology changes the rules of the market, lives of people, or society. According to Picon (2019), "for the past 20 years, architectural practice is facing an extremely rapid pace through the development of digital tools, and this pace is not letting the theorists and historians think, write or make sense of the design methodologies like BIM or Parametric Design. This pace is also not letting the professional standards be set or completely clear." It should be considered that new digital tools and their use are still new to architectural practice compared to the drawing habits and methods that have been ongoing for centuries. Traditional workflows are transformed mainly by new technology; therefore, practices such as architecture must adapt to this recent change. However, when adaptation occurs, practices become irreversibly changed, and their purposes and values are displaced by the qualities and capabilities of new technologies (Kalay, 2006). This displacement is conceptualized as the disruption of the architect and design process in this study.

It was mentioned in the literature review that the development of ICT has constantly disrupted the architect and design processes. Architects have adapted CAD tools that enable the production of contract documents more precisely and efficiently. They were then adapted to computer modeling to reduce construction costs and improve coordination. The development of networking and communication tools has made architects, experts, consultants, and other actors more frequently involved in the design process. VR and AR technologies have enabled the communication between architects and clients to improve in a hybrid world. However, a case study analysis showed that this adaptation process is mostly interrupted by negative values of architects, such as habits, typical workflow, comfort zones, and unwillingness to use new tools.

Negative values create an axis of mindset that does not change at a pace parallel to technological developments. Architects can use new digital technologies; however, their mindsets work analogously. As a result, disruption occurs in the personal sphere of architects with the absorption of new tools, without changing the analog mindset of old technologies. Kalay's (2006) two paradigms, "square peg in the hole" and "horseless carriage", can be used to discuss this disruption.

According to Kalay (2006), two paradigms in architecture happen through disruption. One is about the tools and the other is about architects' perceptions. The first is forcing a square peg into a round hole, which can be defined as new tools that are wrongly implicated or whose usage does not fit the processes that have traditionally been part of architectural design. Using precise drafting tools, where ambiguity and flexibility are required, can be seen as an example of forcing a square peg into a round hole. The relationship between a tool and a task should be functional, as new technology is introduced into practice. Otherwise, the technology results in a poorer practice. This paradigm can explain the frequent use of sketch-up models in architectural practice. Google, a company with no background in construction projects, has developed SketchUp. This tool has become very popular, as it allows architects to model the virtual environment. In a case study, architects defined modeling in Sketchup as cutting a

[3] https://dictionary.cambridge.org/tr/s%C3%B6zl%C3%BCk/ingilizce/disrupt

physical model, which is a traditional habit of the design process. While a similar action can be performed in parametric software with visual coding, the architect's mindset is stuck in a traditional workflow and prefers to use a tool similar to older habits. A similar situation was observed in BIM modeling software such as Revit and Archicad. This software is a complex modeling tool that requires a precise information set. As a result, they could not represent the ambiguity and flexibility that designers needed at the very beginning of a project. The square pegs did not fit the round holes. Visual coding tools such as Dynamo for Revit and Grasshopper for Archicad were developed to increase flexibility and enable software to be used in the first design phases. Therefore, they started rounding them off to fit into the round holes. However, as seen in the case study, while the software has developed to new parametric extents, some architects mentioned that they prefer using tools related to their previous practices, like cutting a physical model. Moreover, the architects who did not show any signs of adapting to new parametric tools themselves frequently mentioned collaborating with new generations who could use these tools.

The second paradigm, *horseless carriage*, describes a state of transformation, where the new technology is viewed through the lens of the practice in obsolete and 'backward' terms. This situation was seen in the early 20th century when the automobile was considered a horseless carriage. This implies a lack of appreciation for the emerging potential of technology in changing the task to which it is applied (Chastain et al., 2002). The paradigm is mainly concerned with the transformation of the designer's perception. The paradigm comes from the first use of automobiles, and people see them as horseless carriages. According to Kalay (2006), this paradigm assumes that the fundamental task does not change, as in the first case. However, unlike the first paradigm, it assumes that the practice of design is not only assisted, but also changed through the influence of new technologies. It can be said that the latest digital tools and their use is still new to the architectural practice compared to the drawing habits and methods that have been ongoing for centuries. Bartling (2019) provided an example of BIM use in this paradigm. He uses the term 'underutilized assets. According to him, while big firms are fully integrated with BIM, they constrain it to a computer-aided design (CAD) approach and limit their capabilities. The habits and methods of historical development of architectural practices continue. Having signed flattened 2D drawings for legal procedures remains standard. Architects in the case study were aware of the developments in BIM, but they saw it as an operational space separated from the concept design or idea world. While BIM is a new perception in the construction industry, architects lack appreciation for this emerging potential technology. This may be because BIM and algorithmic models disrupt the architect's traditional informational workflow. Architects used to be at the center of information, but with BIM, the model is at the center of information. With the traditional workflow, the design information is cut in at each phase, and the architect's own knowledge becomes the main source of the lost information. But in contemporary complex workflow, information is kept in the models mapping on each other until the construction is complete (Figure 7)

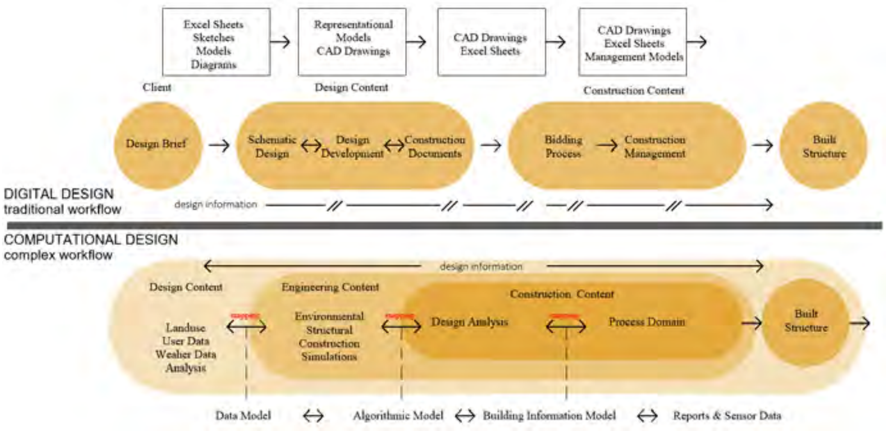

Figure 7. Transformation of design workflow and information management with computational design. Adapted from Pantazis and Gerber (2019).

Hybridization of the architect

"The progressive increase in relations between the virtual world and the real world, in conjunction with the spread of new ICT, is radically changing the ways the two worlds interact, giving rise to hybrid realities, as documented in numerous studies conducted in recent years in literature and multiple applications presented in architecture"(Chiesa, 2020).

Hybridization has recently been discussed in contemporary culture research. While it can be referred to as a term in poststructuralist cultural theory, today, it is used especially in the context of disputes about cultural globalization and the interpenetration of cultures (Ptichnikova, 2020). Nederveen (1995), developing this concept to explain global modernity, argues that globalization has contributed to strengthening the processes of heterogeneity, expressed in the diversity of forms suddenly joining each other and giving rise to entirely new entities. In architectural design, the hybridization concept is mainly used to describe or explain the functional, formalistic, or typologic schemas of designs (Ptichnikova, 2020). Broaweys defines two types of hybridization: the development of materials and the hybridization of reality with digital elements. Chiesa also mentioned two different characteristics of hybridization, pointing out further research. The first is the reduction of boundaries between real and virtual worlds (Sakamoto & Ferré, 2008; Sass & Oxman, 2006; Oxman, 2006; Mitchell, 2005; Milgram & Colquhoun, 1999; Negroponte, 1995). The second is the hybridization of natural and artificial worlds. (Hochberg et al., 2012; Gruber, 2011; Chiesa, 2010; Bar-Cohen, 2006; Benyus, 1997; Gérardin, 1968)

However, in this research, the hybridization concept is not discussed within these definitions. It is used as its first meaning in the Oxford Dictionary:

"The process of breeding together animals or plants of different species or varieties to produce a hybrid"

According to the findings of this case study, architects and digital tools are being bred together to produce a hybrid. It can be said that ICT constantly transforms the habitat of architects as they create extreme conditions. The increasing scale of buildings, increasing level of detail parallel to CAD software, increasing workload with the 3D modeling of every building part, increasing information exchange due to new specialties and actors involved, and the decrease in budget and time limitations define a new habitat. In biology, chemistry, agriculture, or stock farming, to cope with the extreme condition's hybrid species are needed to cope with extreme conditions. Similar to other sectors, architects try to hybridize with digital tools to cope with the complexities of their new habitat.

However, hybridizing with ICT in this new habitat is challenging for architects. Architects can be viewed as species whose boundaries are strictly defined through education. Harrison and Larson (2014) defined species as "populations that are diagnosably distinct, reproductively isolated, cohesive, or exclusive groups of organisms." In this case study, most participants accused the education system of teaching architecture students, such as master architects, who are isolated from other disciplines, while the profession needs otherwise. Parallel to the education system, the first years of working in a classical office structure solidify, creating an analog mindset within architects. Consequently, hybridization with emerging ICTs has become a problematic issue.

Through paradigm-based data analysis of participant profiles, it was observed that some participants were able to hybridize with the technologies of the first digital turn (2D CAD technologies, essential modeling software, etc.). However, their working processes and methods are being disrupted with emerging technologies and the new generation. This result suggests that disruption and hybridization occur in the Mobius circle. In addition, architect hybridization is similar to hybridization in biology in that hybrid species are fertile.

The hybridized architect can be described as a fertile species because it can be seen from the participants' declarations that the hybridization process of the architect is directly linked to the values and mindset of the architect, and values cannot be transferred. Even if the manager of an office tries to force employees to adapt to new technologies, this only happens when the employee feels that it is lacking. Alternatively, in another case, the manager does not try to hybridize with the new technology because he feels safe in his comfort zone. He mentioned that he did not see any lack thereof.

Disruption & Hybridization as a continuous process cycle

Architects are used in traditional workflow. However, their workflow is not capable of solving the new complexities of the digital era. Disruption of habitats is inevitable. After the disruption phase, the hybridization phase starts with computational tools. However, as seen in this case study, the hybridization process was mostly interrupted by the values, beliefs, or attitudes of the architect. In the first phase of hybridization, architects try to use the new software, maintaining an analog mindset. They try to collaborate with the new generation, which is already hybridized with the new workflows being born into. When architects are accustomed to new computational workflows, their mindset adapts to new digital patterns. However, new ICT developments will soon create a new disruption phase, which can be described as a continuous process cycle (Figure 8).

CONCLUSION

It can be said that ICT transformation directly and indirectly impacts architects. Architects are familiar with the direct changes that occur in information technologies. However, the indirect change that emerged as complexity increased was more challenging for architects. With ICT developments, complexity increases, and the habitat in which architects live, produce, and communicate is transformed. Architects with analog mindsets cannot transform their beliefs, attitudes, habits, and comfort zones at the same speed as ICT's transformation. We conceptualized this phenomenon as a disruption of the architect's personal sphere. To compete with these challenges, architects have attempted to hybridize with the new habitat of digital tools. In this sense, they also try to collaborate with the new generations.

With the hybridization process, a new hybrid architecture was created. Maintaining the beliefs, attributes, and values of an earlier period of knowledge, they can use the tools of the new digital era. However, this makes architects see digital developments as simple tools of the operational world or as *horseless carriages*. However, unlike architects with an analog mindset, the new

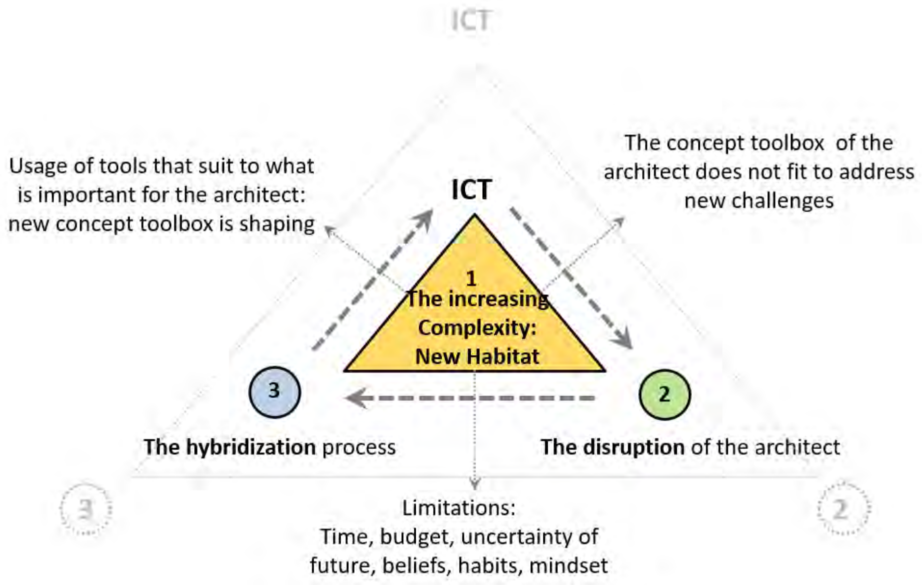

Figure 8. Complexity, Disruption, and Hybridization Continuity

generation born into this digital world can internalize and live much more easily in the digital habitat until new ICT developments disrupt them.

In future research, based on the themes developed in this study, a quantitative research methodology can be used to capture the hybridization level of architects.

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RESEARCH ARTICLE

A Systematic Literature Review of Big Data in Urban Studies

Gülce KIRDAR[1]

[1]Istanbul Technical University, Graduate School, Department of Informatics, Architectural Design Computing, Istanbul, Türkiye

ABSTRACT
The paper aims to explore the use of big data in urban studies by analyzing selected state-of-the-art studies in urban informatics that utilize big data to support urban decision-making. The study conducts exploratory research to gain insight into the association patterns of big data-related concepts. The researchers use the VOSviewer tool to analyze 30 selected references based on keyword occurrences, abstracts, and titles. The study also focuses on how the references handle decision support and examines the relationship network of decision support with other terms. The qualitative and quantitative analysis results are presented to show the association and numeric distribution of the terms. The paper finds that decision support in the selected studies is mainly provided through data-driven computational methods, spatial statistical methods, and mapping of the spatiotemporal pattern of urban phenomena. The reference studies mainly support decisions related to urban activities and functioning, user activities and movement, visiting, and urban perception. The study contributes to presenting the trend in big data studies for urban planning and decision-making.

Keywords: Big data, decision support, urban informatics, data-driven, exploratory analysis

INTRODUCTION

Understanding spatiotemporal changes in user behavior has been a crucial challenge for urban studies. With developments in ubiquitous computing in the 1990s, information technology has permeated urban life through web technologies, information and communication technologies (ICT), sensors, and the Internet of Things (IoT). Pervasive computation hyperextends urban spaces, reinforces multiple interaction networks between users and computers, and consequently generates networked societies and net localities. Net locality is composed of a mixture of digital information and physical localities (Gordon and E Silva, 2011, p.56). In this networked ecosystem, large amounts of data trails are produced. Analyzing the vast volume and variety of data provides researchers with opportunities to understand urban sociability through citizens' digital trails. The information network manages 'the metabolism of urban lives' from environmental, social, and economic aspects, as Townsend (2013, p.6) states. Researchers have begun measuring data, enabling us to control the city's network. The information fallacy enriches the decision-making process.

In this data-rich environment, big data bring about more efficient and effective decision-making in urban planning. The use of big data in urban studies is a relatively new field, and therefore there is a need for more research and exploration in this area. Big data has wide use in urban studies in understanding urban functioning and supporting decisions. Categorizing the references is a crucial step in conducting an efficient literature review in the scope of big data studies. Categorizing references based on interrelationships and grouping them under specific topics in urban informatics allows researchers to better understand hot research topics and identify impactful studies. A systematic and consistent categorization approach ensures a comprehensive and accurate literature review, enhancing research quality. In this regard, this study aims to create a guideline for urban researchers by conducting a systematic literature review.

The research problem explores the potential of big data in understanding urban functioning and supporting urban planning decisions, particularly in the context of urban informatics. The study aims to answer the question of how big data can be utilized to support decision-making in urban studies and to identify the current trends and methods in the use of big data for this purpose. This paper aims to investigate the potential of big data in understanding urban functioning and supporting urban planning decisions. This study poses the question of how to use big data to support decision-making in the context of urban informatics. To that end,

Corresponding Author: Gülce Kırdar **E-mail:** gulcekirdar@gmail.com
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this paper focuses on decision support in urban studies using big data. It provides insight into how big data is utilized in urban informatics studies to understand urban functioning and support decision-making based on the references.

The paper begins with an introduction to the research context, encompassing decision-support systems within data-driven decision-support methods, and the use of big data in urban informatics.

In the second section, the paper delves into the primary subject of this study—big data—by elucidating its definitions and contributions to urban studies, and the locative media data concept which is the scope of the study. The methodology section (Section 3) outlines the qualitative analysis process employed in the study. It is followed by a review of the selected case studies for exploratory analysis in the fourth section. The study presents both qualitative and quantitative results derived from the analysis, in the fifth section. The discussion part (Section 6) addresses ongoing debates concerning the use of big data in urban studies. Lastly, the paper concludes by offering a comprehensive overview of the study, discussing its limitations, and providing recommendations for future research.

LITERATURE REVIEW

Decision support in urban informatics

Advancements in computational systems and the ubiquity of data have given rise to urban informatics. Urban informatics combines theoretical developments in social physics, ecology, urban economics, and location theories with technological innovations in computer systems to understand and model urban functioning (Batty, 2013b). According to Kitchin (2016) and Townsend (2015), "Urban informatics is a field concerning the generation, management, processing, and analysis of urban data" (p. 3, cited in Kitchin, 2017). Big data, advances in ICT, social networks, data from social media platforms, citizen science, participatory practices, and an open data culture contribute to the growth of urban informatics (Batty, 2013b). Urban informatics has been widely used in the following research and application areas: strategies for urban development, planning and policy analysis, management and civic participation, theoretical insights, and knowledge discovery of urban patterns (Thakuriah, Tilahun, and Zellner, 2017). Data-intensive research in urban informatics shifts the focus from computational modeling and simulation of observed phenomena to data-driven modeling, hypothesis generation, and visual data description (Thakuriah, Tilahun & Zellner, 2017).

Data-driven decision support empowers urban planners to make more informed, evidence-based decisions, ultimately leading to better urban policies and outcomes. Decision Support Systems (DSS) are computer-based systems that support users by providing alternatives in the decision-making process for unstructured and multi-criteria problem solutions (Çağdaş et al., 2015). In DSS, the system formalizes the problem and computes the reasoning method to solve it, offering alternative solutions whose selection depends on expert judgment (Drudzel and Flynn, 2002). Decision-support systems have been improved with data-driven analysis methods and big data. Decision-making transforms into a data-driven process, enabled by the expanding scale and types of data available for analysis (Loo & Tang, 2019). Urban planners and designers utilize urban data as evidence in decision-making to support decisions with use cases (Tunçer and You, 2017). More types and amounts of data enable designers to address domain and scale simultaneously, and as a result, they gain more information or evidence to support urban design decisions (Tunçer and You, 2017). Knowledge discovery with data analysis methods generates evidence to be used in design or planning. It offers evidence-based decision support in urban planning decisions. According to Thakuriah, Tilahun, and Zellner (2017, p.33), "The knowledge discovery aspects of data-driven models are important to attract the attention of citizens and decision-makers to urban problems and to stimulate new hypotheses about urban phenomena, which could potentially be rigorously tested using inferential urban models."

Big data

Big urban data has been widely utilized in urban research paradigms to restructure existing computational approaches to urban modeling and simulations, and data analysis methods have been strengthened with machine learning and data mining (Thakuriah, Tilahun, and Zellner, 2017). Big data has three dimensions, which are volume, variety, and complexity (Laney, 2001). Kaisler et al. (2013) describe the big data dimensions as follows:

> "Data volume measures the amount of data, data velocity measures the speed of data creation, streaming, and aggregation; data variety measures the richness of data sources (text, image, video, etc.); data value measures the usefulness of data. In addition to three dimensions, data value measures the usefulness of data in making decisions, and complexity measures the degree of interconnectedness and interdependence in data structures (Kaisler et al., 2013, p. 997)."

Big data approaches support evidence-based decision support through data-driven analysis and decision-making. Urban studies take advantage of big urban data to collect evidence with the intent to support decisions. Batty and colleagues (2012) indicate that integrating big data analysis into urban design leads to informed decision-making about the city's functioning. Big data analytics implement data-driven approaches. Big data analytics support the decision-making process by testing decisions with large amounts and varieties of data. It contributes to the field of evidence-based urban design. Through big data analysis, designers can gain insight into the behavior patterns of the community, which can be valuable evidence in decision-making. The variability of data enables designers to address domain and scale simultaneously, and as a result, they gain more information or evidence to support urban design decisions (Tunçer and You, 2017). As the analyzed data types, scale, and time expand, more valuable information can be gathered and transformed into more useful evidence in the urban decision process. According to Loo and Zhang (2016), "Decision-making becomes a data-driven process" (p. 139). Big data analysis contributes to knowledge generation and decision-making in urban planning by improving the quality, trustworthiness, and legitimacy of decisions (Fredriksson, 2018).

In addition to decision support, the big data approach opens up new possibilities in data collection, analysis, evaluation, representation, and organization methods in urban informatics. Big data paves the way for 'sensing the urban environment' (Batty, 2001). The ubiquity of big data affects the role of urban planners, spatiotemporal resolution, and scaling of urban planning. The role of urban planners expands to include observing changes in urban dynamics ranging from land use and traffic to socio-economy and demography through multiple databases and sensors (Laurini, 2001). Space is disconnected from time with high spatiotemporal resolution of data, and scaling expands from a physical to a socio-economical perspective (Batty, 2001). Big data obtained through digital technology represents a rich and valuable alternative to conventional observation data with high space-time resolution, accuracy, and quality. The use of big data shifts the focus of urban planning to shorter time periods through real-time streaming and user data (Batty, 2013a). Real-time streaming enables urban planners to measure changes and understand user behavior on a shorter time scale (Batty, 2016). Big data presents a valuable source for data visualization and mapping purposes. Big data expands the scale and content of data mapping for information dissemination. The integration of spatiotemporal data on an urban data platform allows for monitoring city performance in real-time and making smarter decisions to enhance performance (Loo and Tang, 2019). Lastly, the big data approach changes urban organization and management methods by fostering the participatory urban design approach.

Big Locative media data

Wilken and Goggin (2017) define locative media as media intrinsically connected to the places and spaces where they are utilized and encountered. These media types are location-based or location-aware, incorporating GPS coordinates, geotagged images or videos, social media check-ins, or any other digital content associated with a particular physical location (Wilken & Goggin, 2017). Locative media data, as defined by Wilken and Goggin (2017), plays a crucial role in understanding the relationship between individuals, places, and digital technology. Locative big data has the potential to greatly impact various fields by providing valuable spatial and temporal information regarding collective user patterns. By integrating locative big data with other datasets, stakeholders can gain a comprehensive understanding of urban dynamics, leading to more effective decision-making processes and improved urban living conditions. Web 2.0 technology, GIS, geotagging, and GPS are the enablers of locative media data (Goodchild, 2007). Locative media data encompasses various types such as geolocated (Adelfio et al., 2020; García-Palomares et al., 2015; Girardin et al., 2008), locative social media (Martí et al., 2017), geospatial (Ensari & Kobaş, 2018; Schlieder & Matyas, 2009), and georeferenced data (Wood et al., 2013).

This study employs Location Based Social Network (LBSN) data as a primary source of locative media data, collected from location-based technologies such as websites, platforms, apps, and online services (W.-C. Lee & Ye, 2014). LBSN and locative media data, both relying on location-based information, provide tailored and interactive experiences for users. By leveraging advanced data analysis tools (Tasse & Hong, 2017), the study aims to achieve an affordable, scalable, and insightful understanding of urban functioning through locative media data from LBSN. This approach enables the exploration of intangible urban aspects from user experiences and perceptions (Martí et al., 2019). LBSN data analysis offers several benefits, such as large sampling, unobtrusive data collection, user bias avoidance, cost-effectiveness, and time efficiency (Martí et al., 2019).

Geolocated data is the data sharing of inhabitants about their activities, perceptions, and interactions when using ICT-based smart mobile applications. Geolocated data (Girardin et al., 2008; Garcia Palomares et al., 2015; Adelfio et al., 2020) has different definitions in the literature: locative social media data (Marti et al., 2017), geospatial data (Kobaş and Ensari, 2018, Schlieder and Matyas, 2009), georeferenced data (Wood et al., 2018; De Choudhury et al., 2010; Shlieder and Matyas, 2009; Manal et al., 2018; Jang et al., 2019; Mart et al., 2017) user-generated content (UGC) (Mora et al., 2018; Girardin et al., 2008), and Volunteered Geographic Information (VGI) (Goodchild, 2007; Jiang et al., 2015; Deng & Newsam, 2017). Geolocated data sources consist of (i) sensing data (GPS traces), (ii) crowdsourcing mapping data (mapping applications like Open Street Map (OPM)), and (iii) LBSN data or social media data (Instagram, Twitter, Flickr, Foursquare). Batty and other researchers (2012) emphasize that analytics of user data provides the possibility to capture the interaction, flows, and networks between the user and the city.

METHOD

This research conducts exploratory research to gain a better understanding of the use of big data in urban studies. In this article, the researcher applies qualitative analysis to a systematic literature review to identify relevant publications on big data in urban studies. The review was conducted on various leading databases of peer-reviewed literature with a focus on articles related to big data, data analysis, urban planning and design, and the contribution of big data analysis to supporting urban planning decisions. The researcher carries out a systematic literature review process using different filters to identify scientific publications as reference studies. A substantial volume of publications have been collected from leading database platforms of peer-reviewed literature, including ScienceDirect, Tandfonline, Arxiv, IEE Explore, Nature, ACM Library, Journal SagePub, and PlosOne. These platforms are renowned for hosting esteemed journals characterized by high impact factors and superior quartile rankings. A total of 30 articles were selected for this study, all of which originate from journals indexed in Q3 or higher quartile rankings. This criterion ensures the inclusion of reputable and impactful sources in the analysis.

In selecting articles for this study, the researcher establishes specific criteria to align with the main research topics: big data, data analysis, urban planning, design, and decision support. The selection process involves two main criteria. First, articles published in journals indexed in Q3 or higher quartile rankings are selected. Second, articles containing relevant keywords, ***big data, geolocated data types (e.g., LBSN, VGI, UGC, SMD), urban analysis, and urban form and functional attributes***, are chosen. The coherence of the articles in terms of purpose, methods used, and results are also crucial for selection. By employing these criteria, the researcher ensures that the selected sources are both pertinent and valuable for the research objectives while upholding academic standards. Based on these criteria, 30 relevant articles have been selected. This study conducts a bibliometric analysis of the selected studies with VOSviewer to describe the overview and evolution of big data use in urban studies, as qualitative analysis.

As explained by Van Eck and Waltman (2014), there are various visualization approaches for bibliometric networks, with three common ones being distance-based, graph-based, and timeline-based approaches. The distance-based approach positions nodes so that the distance between them represents their relatedness, utilizing techniques such as multidimensional scaling. The graph-based approach places nodes in a two-dimensional space and uses edges to indicate relatedness, employing algorithms like the Kamada-Kawai method. The timeline-based approach connects each node to a specific point in time, making it ideal for visualizing publication networks. In this method, one dimension represents time, while the other shows the relatedness of nodes. VOSviewer uses the distance-based visualization approach for bibliometric networks. It specifically employs the VOS (Visualization of Similarities) technique to determine the position of nodes in the visualization (Van Eck and Waltman, 2014).

VOSviewer is a software tool used for constructing and visualizing bibliometric mapping based on the visualization of similarities (VOS) (VOSviewer, 2023). VOSviewer has been utilized for bibliometric analysis of the publications. In VOSviewer, a map is created via the map wizard based on network data, bibliographic data, or text data. In network data, the VOSviewer map and network files are the data source. The bibliographic database and reference manager files within referencing APIs are data sources in bibliographic data and text data (Van Eck and Waltman, 2023). The map of bibliographic data provides connections between items according to co-authorship, co-occurrence of keywords, citation, co-citation, and bibliographic coupling. The map of text data provides relations according to the co-occurrence of terms in the abstract and title. There are two ways of counting occurrences to create links: binary and full counting. Binary counting counts how many documents the term occurs in at least once. Full counting counts how many occurrences of the term occur in all documents (Van Eck and Waltman, 2023).

In this study, four networks were created from (i) abstract, (ii) title, (iii) keywords, and (iv) citations. The software (VOSviewer) reads data from reference manager files. Before visualization in VOS software, the citations of the publications were conveyed into reference files (RIS) in Mendeley. The RIS files are the input of this network. The abstracts of the references were used to create a network. The terms were collected under specific groups, based on the widely used terms related to the research topic, scope, and method. A dictionary was created to collect term groups with similar meanings. To create a dictionary, first, all the keywords extracted by the VOSviewer Wizard are obtained and converted into a comma-separated file (CSV) format. In this way, the keywords are defined. During the scrapping process, there is an option to scrape the terms as word groups. With this option, terms like city and smart city, or data and big data, are not confused and are considered as separate terms. The dictionary is imported into the map wizard as a thesaurus file. A thesaurus file has two columns: a label column and a replace-by column. The first line includes the keywords, while the second line contains the corresponding terms, defined by the researcher, to merge synonyms and similar-meaning words into a single term. For instance, data-related terms are grouped under big data, activity places (venues, restaurants, etc.) are grouped under urban activity, and decision support and decision-making terms are grouped under decision support. Different city names are grouped under city-level analysis. The plaza, public space, square, recreational site and recreational area, leisure, urban park, and park are grouped under urban POS category. Urban POS stands for the urban public open space. Geolocated data, geotagged data, georeferenced data, location information, geo-tag, geospatial, location-based social network (LBSN), and volunteered geographic information (VGI) data are grouped under geolocated data. Visualization-related terms and methods are grouped under data visualization. Similarly, different statistical methods are grouped under spatial statistical techniques, and various social media data-related terms are grouped under social media network. Accordingly, 725 terms were grouped into 84 items extracted by grouping. In this way, the occurrence of each term is increased. The dictionary database is shown in **Appendix B.**

The group names were extracted by the researcher from the keywords that indicate the scope and topic of the studies, as shown in **Table A.1**, which displays the reference studies. The network was created by extracting the text data from abstracts. The full counting method was employed to increase the occurrences of the terms and complicate the network. The minimum number of occurrences was set at 8, and 51 items met the threshold. Based on the relevance score, 90% of the items were selected. For 45 items, 3 clusters of 15 items were created each. In this network, there were 45 items, 874 links, and a total link strength of 16,362. For the title network, the same dictionary was used to compile closely related terms under the same group. The words in the title of the references were imported from RIS files as text data and counted using the full counting method. Eighty-six items were obtained, and twenty of them occurred more than 2 times. As a result, 3 clusters were obtained with 42 links and a total link strength of 58. **Table A.1** displays the exported results of the terms in the abstracts of the references. In a similar vein, another map was created based on bibliographic data according to keyword co-occurrence. The input information about the publications was taken from the reference database in RIF format. The same dictionary was used to group the terms in the keyword. In the keyword network, there were 26 items with 3 clusters, 112 links, and 166 total strengths. The keywords are listed with their occurrences and relevance scores in **Table A.2**. Another network map was created for citations of the authors using the bibliographic database. The documents were imported via the Digital Object Identifier (DOI) of the publication. Citation is the unit of analysis for the documents. The threshold for the citation of each document was set at a minimum of 10. Among 27 documents, 19 items met the threshold. For these 19 items, 4 clusters were created with 33 links and a total strength of 65. Citation data are listed with their occurrences and relevance scores in **Table A.3.**

Data visualization includes network visualization, overlay visualization, and density visualization. All of the networks were analyzed based on the publication years in overlay visualization and occurrence frequency in density visualization. In ***network visualization,*** items are represented by labels and circles (Van Eck and Waltman, 2023). The size of the label and circle depends on the weight of the items. The items are connected with links, which display the relatedness of the two publications in terms of co-citation, keyword, abstract, title, etc. ***Overlay visualization*** utilizes the same network, but the colorization changes based on quantitative information such as the publication year, citation score, or impact factor. ***Density visualization*** indicates the density of the clusters based on the number of neighboring items and their weights, represented by colors ranging from blue to green to yellow. Accordingly, as the number of items increases in the neighborhood of a point within their weight, the color changes from blue to yellow (Van Eck and Waltman, 2023). Overall, this methodology provides a clear and coherent approach to identifying and analyzing relevant articles on the use of big data in urban studies and provides a detailed explanation of the processes and tools used in the analysis.

REFERENCE STUDIES

Researchers have shown an increased interest in the use of geolocated data coming from LBSN and social media networks in urban analysis to generate useful knowledge about cities' functioning and livability within the scope of the big data approach. As the literature review demonstrates, the locative information obtained from geolocated data is useful to reveal the ephemeral layer of cities: where people are concentrated (Garcia et al., 2015; Cranshaw et al., 2011; Kisilevich et al., 2013), what the common travel patterns are (Batty et al., 2012; Sun et al., 2016), and visit patterns (Girardin et al., 2008), as well as the urban form factors driving the use of a place (Lie et al., 2019; Zhang & Zhou, 2018).

In terms of urban activities, Wu and colleagues (2016) employ POI data from Foursquare check-ins and online real estate data for land price analysis in order to uncover the relation between POIs and land price. Jiang et al. (2015) use the Yahoo platform to estimate land use based on POI data and achieve a higher level of accuracy compared with traditional methods. Zhang and Zhou (2018) utilize Foursquare check-in data with other spatial attributes through regression analysis to examine how the attributes, locations, and accessibility of a park affect the check-in number in the park. Kobas and Ensari (2018) enrich social network data analytics by overlapping multiple datasets - including real estate data, geolocation from social media (Instagram) within its context, accessibility data from public transportation, and commercial resources - with the intent to examine demographic and economic trends through data visualization.

The location data (check-ins) from Foursquare is employed to identify city venues and POIs (Sun et al., 2016). Cranshaw and colleagues (2012) use Foursquare check-ins within Twitter tweets to understand the collective movement patterns of users and identify lively urban areas. Abbasi and colleagues (2015) use a text mining approach to reveal the trip purposes of tourists from tweets using Twitter. Marti and other researchers (2017) identify successful public areas through Foursquare and analyze their relation with historic centers and the main axes of the city to understand the correlation between location and the vibrant characteristics of the space. Text data from Twitter has been used to identify public sentiment about social life (Tuncer and You,

2018) and urban happiness (Guo et al., 2021). Image data from geolocated services (such as Instagram and Flickr) is useful for defining the place identity of the public. Huang et al. (2021) and Jang et al. (2019) utilize images and texts to generate cognitive mapping referring to Lynchian elements.

User-generated and sports data apps (fitness and other sports applications) have been studied to understand the sports habits of citizens and detect popular exercise areas (Mora et al., 2018; Delhoyo et al., 2018; Balaban and Tuncer, 2016). Balaban and Tuncer (2016) measure the runnability of a city and factors related to sports activities of citizens using fitness data from mobile applications, crime data, weather data, and spatial data to understand the sports habits of residents, and accordingly, predict recreational spaces in the city. Mora and colleagues (2018) overlap GPS tracking data with mobile applications used for sports activities to create knowledge aiming to support decision-making for planning recreational areas. Furthermore, travel patterns in public transportation have been evaluated using travel card data (London Oyster card) to understand daily travel flow and the volumes in hubs on the rail network (Batty et al., 2012). Photo-sharing platforms (Panoramio and Flickr) have been utilized for spatiotemporal analysis to identify attractive places (Kisilevich et al., 2013; Garcia-Palomares et al., 2015) and estimate the number of visitors at tourist attractions (Wood et al., 2013; Girardin et al., 2008). Manal and colleagues (2018) analyze viewpoints and view scenes/tags of Flickr photos to elicit preferred heritage attributes and their significance. This research examines related works under the subjects of (i) urban activities and density, (ii) user movement and visits, and (iii) urban perception. ***Table 1*** exhibits related studies using LBSN data in urban research.

RESULTS

Figure 1 and **Figure 2** present quantitative facts about the terms as clustered pie charts and pie chart diagrams, respectively. The first diagram **(Figure 1)** displays the occurrence of each term group. Notably, the most occurred term groups are city (73), city scale analysis (65), research (60), place concept (55), big data (50), and social media network (40). The second most occurred term groups include place identity (34), urban points of interest (32), spatiotemporal analysis (30), urban functioning (30), user (29), urban activity (27), neighborhood (24), visit (24), analysis (22), points of interest (22), check-in (21), location (21), sentiment analysis (20), photo-sharing services (20), quantitative (20), urban decision support (20), and user activity (20).

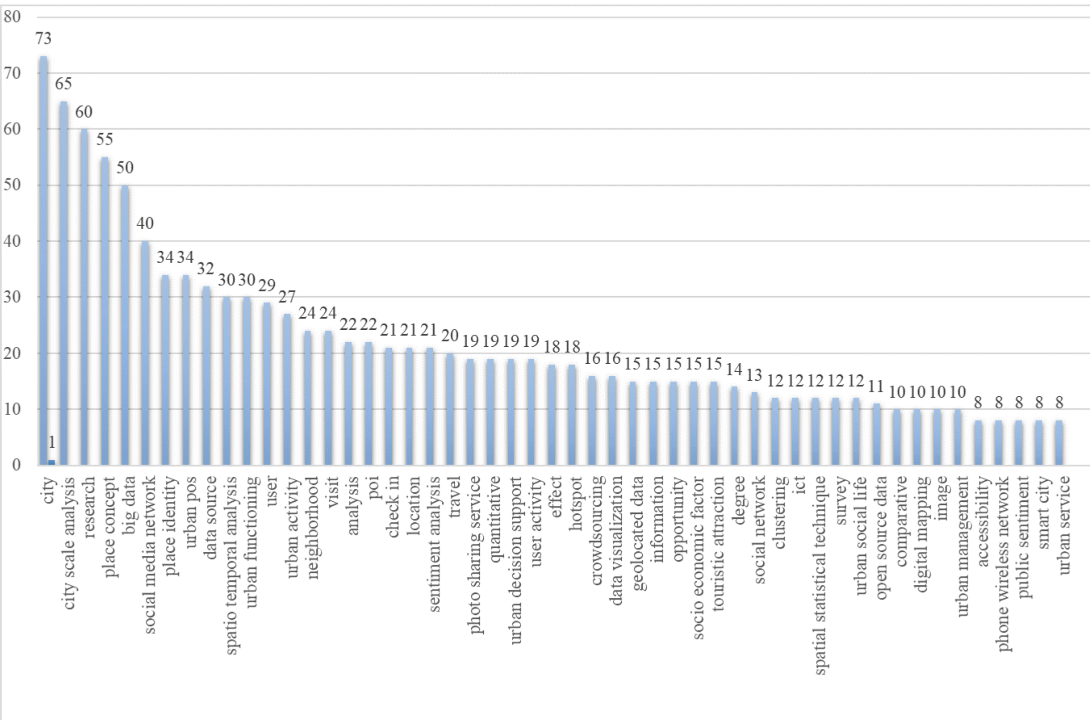


Figure 1. Clustered bar chart graphic showing the occurrence of the terms.

In the reference studies, 54% of the overall terms are related to research topics, which primarily focus on urban phenomena, place, context, and the scale of the studies. **Figure 2** displays the distribution of terms based on specific categorization. Among the most cited terms, city scale analysis (city names), place concept, neighborhood, urban points of interest (parks, green areas, plazas), touristic attractions (historic city centers, cultural sites), points of interest (POIs), and hotspots (city centers) define the location.

Table 1. Reference studies to reveal the urban activities, user movement, density, perceptions, and preferences.

Subject: Urban activities (POI) and user density **aim:** *to understand land use, POIs, social life, land value, socio-economic trends*						
Study	**Reference**	**Topic/ Scope**	**Keywords**	**Data types and tools used**	**Methodology**	**Decisions supported**
Spatial and Social Media Data Analytics of Housing Prices in Shenzhen, China	Wu, C., Ye X., Ren, F., Wan, Y., Ning P., Du, Q. (2016).	**LAND VALUE** the factors affecting house prices / the impact of POI on land value	Housing prices, urban China, big data, spatial patterns, geographically weighted regression.	Check-in data and online real estate data from websites	Kernel density estimation (KDE) for POI density and the hedonic price method (HPM) to estimate pricing and the geographically weighted regression (GWR) method for spatial analysis	To support decisions related to land value
Mining Point of Interest Data from Social Networks for Urban Land Use Classification and Disaggregation	Jiang, S., Alves A., Rodrigues, F., Ferreira, J., Pereira, F.C. (2015).	**LAND USE -POIs** the relationship between land use attraction points through social media platforms	Information extraction Points of interest Volunteered geographic information	Yahoo platform (for POIs) and land use data	Machine learning for POI classification (destiny-based clustering) and estimation of the land use based on POIs	To support decisions related to land value
Crowdsourcing functions of the living city from Twitter and Foursquare data	Zhou & Zhang (2016)	**URBAN FUNCTIONS (LAND USE)** the relation between urban functions and social sensing	Social media data Geographic Information Systems City characteristics Urban planning	geo-referenced tweets from Twitter and Foursquare check-ins of venues (restaurant/store/ cinema)	Foursquare API to classify venues and Support Vector Machine (SVM) to classify tweets/ PostGIS for mapping and R for analyzing	Support decisions related to urban functions
Quantitative Comparison of Open-Source Data for Fine-Grain Mapping of Land Use	Deng, X., Newsam, S. (2017)	**URBAN FUNCTIONS (LAND USE)** the comparison of land uses in administrative data and activities in VGI	Land use, points of interest, volunteered geographic information (VGI)	Google Places listings Yellow Pages and Bing Map Open Street Map	Web scraping and quantitative evaluation with statistics test for comparing pairwise comparison of administrative and VGI data	Support decisions related to urban functions and land use planning
Understanding User Activity Patterns of the Swarm App: A Data Driven Study	Lin S., Xie R., Xie Q., Zhao H., Chen Y. (2017)	**URBAN ACTIVITIES** the comparison of urban activities in different cities	Location-Based Services; Check-In, Swarm App, Spatial-Temporal Analysis, City Computing, Human-centered computing	Foursquare check-ins	Web scraping of Foursquare data and spatio-temporal analysis within the correlation tests	Support decisions related to urban activities and user activity pattern
Measuring urban activities using Foursquare data and network analysis: a case study of Murcia	Agryzkov T., Martí P. , Tortosa L. & Vicent, J.F. (2016)	**URBAN ACTIVITIES** urban activities and social networks	Urban analysis Social networks analysis Street networks PageRank algorithms Data visualization	Foursquare check-ins and user comments	Web scraping of Foursquare data of venues Analysis through network centrality algorithm Compare field study with social media analysis in terms of venue categorization	To support decisions related to user preferences on urban activities
Social Activity in Gothenburg's Intermediate City: Mapping Third Places through Social Media Data	Adelfio, M., Serrano-Estrada, L., Ciriquian P.M., Kain, J., Stenberg, J. (2020)	URBAN ACTIVITIES - Urban sprawl Understanding urban activities in the intermediate cities	Intermediate city third places Social media data (SMD)	Foursquare Twitter Google Places	Web scraping Descriptive analysis	To support decisions in urban planning related to urban sprawl
Revisiting the Spatial Definition of Neighborhood Boundaries: Functional Clusters versus Administrative Neighborhoods	Marti, P., Serrano-Estrada, L., Nolasco-Cirugeda, A., Baeza, J.L.(2021)	**NEIGHBORHOOD BORDERS** define the borders of neighborhoods based on functions and compare with	Neighborhood boundaries, functional clusters, urban economic activities, Google Places social networks	Google Places listings	Web scraping Functional clustering	To support decisions related to urban economic activities
Social Activity in Gothenburg's Intermediate City: Mapping Third Places through Social Media Data	Adelfio, M., Serrano-Estrada, L., Ciriquian P.M., Kain, J., Stenberg, J. (2020)	**URBAN ACTIVITIES -** Urban sprawl understanding urban activities in the intermediate cities	Intermediate city third places Social media data (SMD)	Foursquare Twitter Google Places	Web scraping Descriptive analysis	To support decisions in urban planning related to urban sprawl

The context of the studies makes up 13% of the most occurred terms, including city, big data, geolocated data, information, urban decision support, and urban management. Urban phenomena account for 28% of the occurrences, encompassing urban functioning, place identity, user activities, urban activity (user movement, sports), travel, visit, urban social life, and socio-economic factors. Data sources represent 19% of the overall terms. Widely used data sources for analysis include geolocated data sources, social media networks, Twitter, check-ins (Foursquare, Swarm, Weibo), photo-sharing services (Flickr, Panoramio), open data sources (real estate listings, Airbnb listings, websites), and surveys. Analysis methods constitute 21% of the overall terms, featuring spatiotemporal analysis, sentiment analysis, data-driven analysis, computational methods, digital data mapping, data visualization, spatial statistical techniques (statistical methods), clustering, comparison, and classification. The results indicate that big data studies have been employed to understand urban dynamics from various perspectives, ranging from social and economic factors to user activity, movement, visit, and perception. Numerous data-driven analysis methods have been utilized to comprehend the spatial distribution of urban phenomena, extending from statistics to visualization and mapping. The results also showcase the diversity of geolocated data sources, grouped under geolocated data, used to measure the pulse of places.

The network results of the text data analysis of the abstract terms (Url-1) are shown in **Figure 3**. This network is normalized with association strength. In this network, **Cluster 1** (represented in red color) includes terms related to urban activities, urban

Table 2. Reference studies to reveal the urban activities, user movement, density, perceptions, and preferences.

Impact of Airbnb on the Gentrification Process: The Case of Rasimpaşa Neighborhood	Uzgören, G. & Türkün, A. (2018)	**GENTRIFICATION THROUGH ACCOMMODATIONS**	Airbnb, gentrification, displacement, globalization.	Airbnb accommodation properties and rental price (real estate web site)	Mixed research methods Quantitative data with web scraping, Survey field study with people, Comparing the two analysis methods	To support decisions related to land use planning regarding gentrification
Recreational visits to urban parks and factors affecting park visits: Evidence from geotagged social media data	Zhang & Zhou (2018)	**PARK USE** understanding the effective factors of urban park use	Park use, geotagged check-in data, social media, park attributes, park location	Social media platform (Weibo) check-ins and shares and spatial data	Statistical methods (regression) to investigate the correlation Weibo API (4year datasets) to scrape recreations ArcGIS for spatial analysis	To support spatial decisions related to the use of public open space
Deciphering the recreational use of urban parks: Experiments using multi-source big data for all Chinese cities	Li, F., Li, F., Li, S. Long, Y. (2019)	**PARK USE** The relationship of urban park use with other social reinforcement in different cities	Weibo check-ins Park attributes Regression models Park usage China	Social media platform (Weibo) check-ins of the park, population GDP per capita	Weibo API check-ins for park visits Multiple linear regression models to analyze the affecting factors ArcGIS to data mapping	To support spatial decisions and socio-economic trends related to the use of public open space
Web Scraping and Mapping Urban Data to Support Urban Design Decisions	Kobas & Ensari (2018)	**URBAN ACTIVITIES AND USE** understanding how people use the urban area and how urban use creates spatio-temporal change	Geospatial data, Urban data, Urban design decision support, Web scraping	Instagram shares, data from online food order/delivery, online real estate, land use data, public transportation	Web scraping methods with Python apis Data visualization for decision support with Meerkat plugin of Grasshopper	To support urban design decisions regarding socio-economic trends
Subject: User movement, travel and urban sports **aim:** *to detect travel routes and identify recreational/sport areas*						
Study	**Reference**	**Topic/ Scope**	**Keywords**	**Data types used**	**Methodology**	**Decisions supported**
Smart Cities of the Future.	Batty M., Axhausen K., Fosca G., …. Portugali Y. (2012).	**DAILY TRAVEL MOVEMENT** monitor daily flow of community and volume of public transportation	Geotagged photographs, Photo-sharing services, Spatial distribution, Tourist attractions	London Oyster travel data	Construct multimodal trips (origins and destinations) Calculate movement flows and passenger volume to estimate optimum passenger capacity	Support decisions related to mobility and travel
Visualizing urban sports movement	Balaban and tunçer (2016)	**Urban sports** the runnability of the city reveals related factors of sport	Sports activity, big data, urban visualization, fitness applications	Data from mobile applications fitness related / crime data/ weather data/ spatial data/ fitness data	Integrate endomondo fitness application data with gps data as relational databases in mysql data visualization of different datasets in gis	Support decisions related to urban sport activities
Analysis of Social Networking Service Data for Smart Urban Planning	Mora, H., Perez-Delhoyo, R., Parades-Perez, J.F., Molla-Sirvent, R.A. (2018).	**URBAN SPORTS** identify the most preferred fitness route	Social networks, ambient behavioral analysis, urban planning, decision making, sustainability, accessibility	The social network platforms used for sport activities/data from mobile applications (GPS tracking data)	Scrape geolocation data Establish route map and overlap street view to understand the frequently-visited places and the reason for selection	Support decisions related to recreational areas
Subject: User density, perception and preferences ***aim:*** *to identify attractions and points of interests (POIs)/understand the purpose and reasons for visit/offer proposal for visit*						
Study	**Reference**	**Topic/ Scope**	**Keywords**	**Data types used**	**Methodology**	**Decisions supported**
Using social media to quantify nature-based tourism and recreation	Wood, S.A., Guerry, A.D., Silver J.M., Lacayo, M. (2013).	**NATURAL PARKS** define visitor density/rate in year and week	Sports Activity, Big Data, Urban Visualization, Fitness Applications	Flickr georeferenced data	Scrape visitation data through Flickr, Calculate the visitation rate, Estimate user-days per year and each week Compare visitation rate with real visits through statistical analysis ANCOVA	To support decisions related to recreational visits
Automatic construction of travel itineraries using social breadcrumbs	De Choudhury, M., Feldman, M., Amer-Yahia, S., Golbandi, N., Lempel, R., & Yu, C. (2010).	**TRAVEL ROUTES** create travel itinerary to monitor visitors' route	Flickr, geo-tags, mechanical turk, orienteering problem, social media, travel itinerary	Flickr georeferenced data	Scrape photos from Flickr API Take POIs from Yahoo and combine with photos' geolocation photo-POI mapping and construct time paths to sequence based on visiting time Create itineraries from time paths, justify with surveys	To support decisions related to visitor routes

functioning (urban function and urban form attributes), and neighborhoods. According to the keywords in this cluster, the studies focus on urban activity and functioning attributes within the socio-economic and socio-cultural attributes of neighborhoods. Socio-cultural factors are associated with the diversity, ethnicity, age, and gender of the citizens within the cultural attributes of the city, while socio-economic factors are associated with economic trends, housing, and real estate data. Clustering analysis of check-ins is useful within the spatial statistical technique to measure density in urban activities and specify points of interest (POIs). Socio-economic data aids in understanding the social and economic value of urban activities. This cluster comprises 15 terms, with the most frequent ones being decision support, digital mapping, urban activity, urban functioning, hotspot, check-in, big data, and user **(Figure 3).** This cluster is classified as ***urban activities and density.*** The studies in this cluster aim to support decisions in urban activities and functioning. The results of these studies would be useful for decision-making in neighborhood density and activities **(Figure 3).** Based on the occurrence of the terms in the abstract, the most associated terms are, respectively, contextual concepts (city, place concepts), then urban phenomena (urban POS (public open space), functioning, social life, and identity), and lastly, these urban phenomena are connected with analysis methods (data-driven analysis, mapping, and visualization).

Table 3. Reference studies to reveal the urban activities, user movement, density, perceptions, and preferences.

Utilising Location Based Social Media In Travel Survey Methods: Bringing Twitter Data Into The Play	Abbasi A., Rashidi T.H., Maghrebi M., Waller S.T. (2015)	**TRAVEL ROUTES** Twitter data for travel demand analysis (as topic modeling)	Social media data, Crowdsourcing, Travel attributes, Twitter, Tourists, Travel pattern	Twitter data	Detect activity location from geolocation through Twitter Search API - Data mining of personal tweets' location to query the activity location Text mining techniques to understand trip purpose from tweets	To support decisions related to travel pattern
Photographing a City: An Analysis of Place Concepts Based on Spatial Choices	Schlieder and Matyas, (2009)	**TOURISTIC ATTRACTIONS AND VISITING ROUTE** analyze point of views (POV) of photographers	Geospatial semantics Place concepts Geographic recommender systems Social tagging	Flickr georeferenced data	Measure the popularity of POV (point of visit) with Flickr API Cluster the POVs with clustering algorithm (Heatmapper) To understand the visit route of users	To support decisions related to visitor density at touristic pois
Digital Footprinting: Uncovering Tourists with User-Generated Content	Girardin, F., Calabrese, F., Fiore, F. D., Ratti, C., & Blat, J. (2008).	**TOURISTIC ATTRACTIONS AND VISITING ROUTE** define user-related spatio-temporal data	Pervasive user-generated content Reality mining Information visualization	Flickr georeferenced data and cell phone network data	Scrape visit data through Flickr Compare with statistical analysis (standard deviation analysis) use KML* for visualization of geolocated data process data into Google Earth	To support decisions related to visitor density and movement at touristic pois
Towards acquisition of semantics of places and events by multi-perspective analysis of geotagged photo collections	Kisilevich, S., Keim, D., Andrienko, N., & Andrienko, G. (2013).	**ATTRACTIVE CITY CENTERS** analyze events and places using geotagged photo collections	Spatio-temporal clustering Semantic enrichment Geotagged photo collections	Panoramio and Flickr photo shares Multisource data types (geolocation and text data)	Analysis of movement data Define spatio-temporal clusters of visit using DBSCAN* algorithm/ Apply semantic analysis (titles/tag/content/GeoNames) with text mining and grouping	To support decisions related to visitor density and movement at touristic pois
Identification of tourist hot spots based on social networks: A comparative analysis on European metropolises using photo-sharing services and GIS	Garcia-Palomares, J.C., Gutierrez, J., Minguez, C. (2015).	**TOURISTIC ATTRACTIONS** analyze tourist dynamics in tourism geography	Geotagged photographs, Photo-sharing services, Spatial distribution patterns, Tourist attractions, European cities. Spatial statistics	Panoramio photo data and GIS spatial data	Scrape Panaramio API and Flickr API Apply spatio-temporal analysis in ArcGIS to identify interest points and determine tourist dynamics Identify clusters with statistical technics in GIS (Moran I)	To support decisions related to visitor density touristic pois
Identifying the City Center Using Human Travel Flows Generated from Location Based Social Networking Data	Sun, Y., Fan H., Li, M., Zipf, A. (2016).	**ATTRACTION CENTERS** define activity centers and venues in the city	Center identification, Human mobility, Local Getis-Ord, DBSCAN, Grivan-Newman	Foursquare check-ins and mobility data (travel data from public transportation and taxi) GPS tracking data	Conduct spatial statistical analysis (DBSCAN/ Grivan-Newman* and LGOG* methods), Detect hotspots and clustering of hotspots (attraction centers), Identify the borders of city center with different clustering methods	To support decisions related to user density and movement at pois
The Livehoods Project: Utilizing Social Media to Understand the Dynamics of a City	Cranshaw, J., Hong, J. I., & Sadeh, N. (2011)	**ATTRACTION CENTERS** livehoods: dynamic areas in the city urban vibrancy/ vitality	smart cities, location-based social networks, Foursquare, check-ins	Foursquare check-ins and Twitter data	Clustering model for mapping based on collective behavior of users, Combine quantitative methods with qualitative methods through interviews for identifying livehoods	To support decisions related to the attractiveness of hotspots in the city center
Using Locative Social Media And Urban Cartographies To Identify And Locate Successful Urban Plazas	Marti, P., Serrano-Estrada, L., Nolasco-Cirugeda, A. (2017)	**URBAN PLAZAS** identify driving factors of successful plazas (relation with urban axes)	Public space Plaza Square Social networks Livable spaces Social spaces	Foursquare georeferenced data (check-ins)/ category/ total users/ pictures and shares with spatial data from cartography	Data collection through Foursquare API classification of venues/ Detect most popular plazas and compare with spatial data (from cartography)	To support decisions related to the attractiveness of urban squares
Mapping historic urban landscape values through social media	Manal, G., Rodersb, A. P., Teller, J. (2018)	**HISTORICAL URBAN HERITAGE SCAPE** the analysis of the view- point from Flickr photos to elicit preferred heritage attribute	Historic urban landscape Social media Flickr Cultural heritage Everyday landscape	Flickr georeferenced photos/tags	Map the spatial distribution of Flickr photos to identify preferred heritagescape. Create classification model to elucidate the heritage attributes Reveal tag analysis to determine heritage significance via semantic map	To support decisions related to visitations, visitor perception and preferences
Understanding Happiness in Cities using Twitter: Jobs, Children, and Transport	Guo, W., Gupta, N., Pogrebna, G., Jarvis, S.A. (2021)	**PUBLIC SENTIMENT**	Happiness, Social media data, City demographics Socioeconomic parameters, Positive sentiments	Twitter data	web scraping of tweets from Twitter apply natural language processing (NLP) techniques sentiment analysis	To support decisions related to citizen satisfaction from socioeconomic conditions for urban happiness

Cluster 2 (represented in green color) includes terms concerned with social life, place identity, and public sentiment. According to the keywords in this cluster, the studies deal with identifying public sentiment, place identity, and urban social life through sentiment analysis of images and Twitter. The place identity group encompasses the image of the city constructed through Lynchian elements and cognitive mapping, while the social life group encompasses the everyday life habits of citizens. Sentiment analysis of Twitter is useful for revealing public sentiment and social habits. Sentiment analysis of images from photo-sharing services is useful for revealing place identity elements. Data visualization is the method used to represent place identity and sentiments. This cluster involves 15 items, with the most frequent ones being crowdsourcing, data visualization, image, place identity, public sentiment, social life, and sentiment analysis. This cluster is classified as ***urban perception.*** Accordingly, the studies in this cluster aim to support decisions in place relationships in terms of place identity and sentiment. The results of these studies would be useful for decision-making in user perception of urban places. The analysis unit of the studies in clusters 2 and 3 is the city scale **(Figure 3).**

Table 4. Reference studies to reveal the urban activities, user movement, density, perceptions, and preferences.

Exploring public sentiments for livable places basedon a crowd-calibrated sentiment analysis mechanism	Tuncer, B. You (2018)	**PUBLIC SENTIMENT** the effects of public sentiments of social networks in the domain of place design	Sentiment analysis Twitter, Machine learning algorithms Pattern classification Livable places Crowd-calibrated sentiment analysis mechanism	Twitter and Instagram hashtags and content	Web scraping of tweets from Twitter sentiment analysis Develop a crowd calibrated geo-sentiment analysis mechanism Classify the positive-negative-neutral sentiments	To support decisions related to urban design considering public sentiments
The image of the City on social media: A comparative study using "Big Data" and "Small Data" methods in the Tri-City Region in Poland	Huang, j., obracht-prondzynska, h., kamrowska-zaluska, d., sun, y., & li, l. (2021).	**Public image**	Kevin lynch city image social media analytics tri-city poland	Instagram posts and hashtags	Web scraping of hashtags social media data analytics lynch methods mapping-survey, gis analysis of administrative data clustering analysis (dbscan- kde) comparison of three datasets	To support decisions related to urban identity, urban image
Crowd-sourced cognitive mapping: A new way of displaying people's cognitive perception of urban space	Jang, k. M., & kim, y. (2019).	**Public image**	Cognitive mapping, georeferenced text data, crowd-sourced cognitive map, urban identity, visualization	Textual data of instagram hashtags	Scrape instagram photos and photo data Create crowdsourced cognitive map using instagram hashtags	To support decisions related to urban perception through cognitive map, evaluation of urban identity

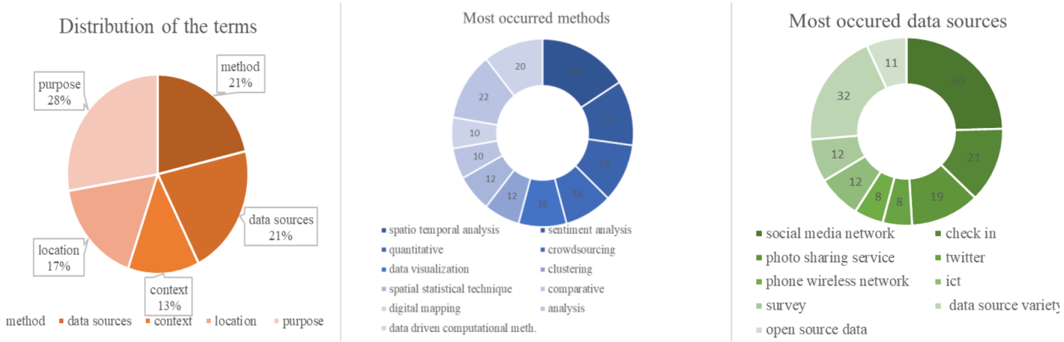


Figure 2. Pie chart graphics displaying distribution of the terms.

Cluster 3 (represented in blue) includes terms related to tourism, visit, urban POS, travel, and accessibility. Based on the keywords, the studies deal with visits to urban POS, touristic visit sites, and visitation rates. Photo-sharing services are the geolocated data source used to measure density in visited places. Phone and wireless networks are other data sources to track visitors' movement and density. The spatiotemporal patterns of visitor and travel data have been revealed in the studies. This cluster comprises 14 items, with the most frequent ones being travel, accessibility, tourism, urban POS, visit, spatiotemporal pattern, photo-sharing service, and phone wireless network. This cluster is classified ***as user movement and visit.*** Accordingly, the studies in this cluster aim to support decisions in visits and travel. The results of these studies would be useful for decision-making by visitors and mobility or accessibility **(Figure 3).**

Table 5. The terms in these three clusters.

Cluster	**Cluster Color**	**Terms in this cluster**
Cluster 1	Red	urban activities, urban function, urban form attributes, neighborhood, socioeconomic attributes, sociocultural attributes, urban density
Cluster 2	Green	public sentiment, place identity, urban social life, sentiment analysis, images, Twitter, urban perception
Cluster 3	Blue	tourism, visits, public open spaces, touristic visit sites, visitation rates, user movement, accessibility, visit and travel, urban POS (public open spaces)

The overlay visualization map **(Figure 4)** illustrates the chronological development of the reference studies. The years in the legend represent the average publication year of the references. As seen, the publication years of the sources range from 2015 to 2018, indicating that they are up-to-date and closely related. There is a notable increase in published references over the five-year span. Studies related to the use of geolocated data began around 2008 and accelerated until 2018, showing that big data is a popular research topic in urban studies. The initial studies using big data were associated with urban movement (visit and travel) and points of interest (POIs) through the use of photo-sharing services (Flickr, Panoramio) and tracking from phone and wireless

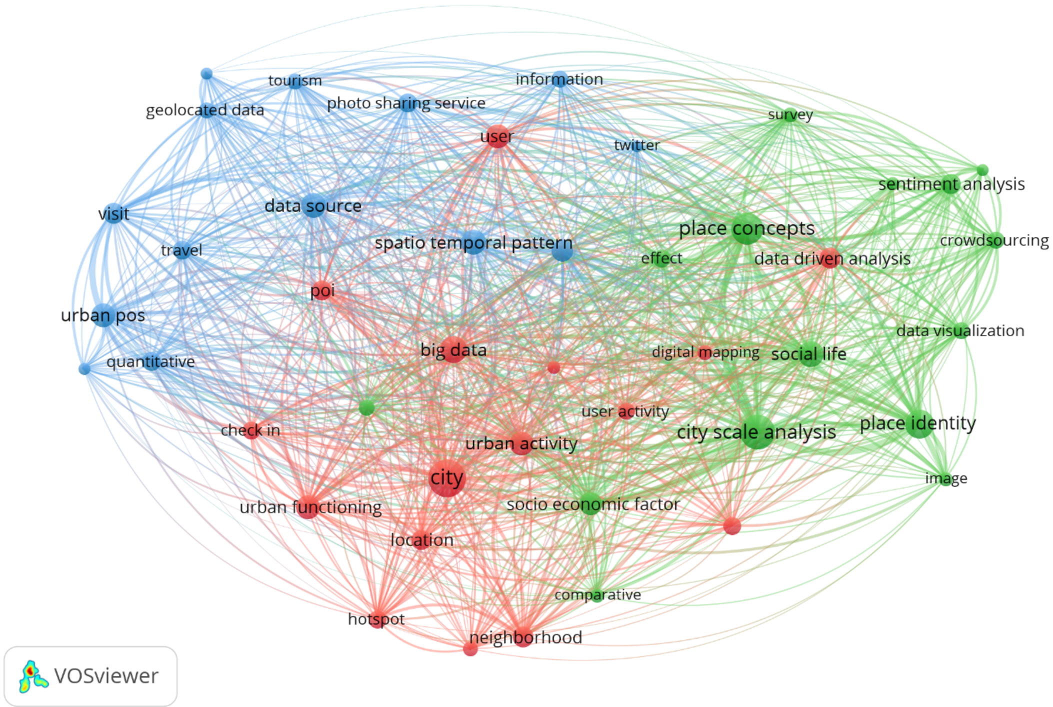


Figure 3. Network visualization results.

networks around 2010. With the ubiquity of social media and check-in data (Twitter, Instagram, Foursquare, etc.) and various analysis methods, research topics expanded to include urban activities and perceptions around 2015 and later. The density map **(Figure 5a)** displays that city, city scale analysis, big data, place concepts, place identity, social media network, spatiotemporal pattern, and social life are the most densely clustered items. Cluster density results **(Figure 5b)** show that cluster 1 (urban function) is the most densely clustered group, cluster 2 (urban perception) is moderately dense, and cluster 3 (urban movement) is the least dense cluster.

Figure 6 presents the network visualization of the titles, while **Figure 7** displays the network visualization of the keywords based on their co-occurrence. Both networks provide information about the research topic, applied methods, and geolocated data types. The results of the title and keyword networks support the classification derived from the abstract text. Accordingly, the ***urban activities and density*** cluster **(Cluster 1)** includes check-in, user activity, urban activity, digital mapping, and data-driven analysis. Based on the keyword network results, urban activities, functioning, and points of interest are clustered together. The urban perception cluster **(Cluster 2)** comprises public sentiment, sentiment analysis, place identity, crowdsourcing, place concepts, and spatiotemporal patterns. Keyword network results confirm the clustering of public sentiments, place identity, urban activities, functioning, and points of interest.

The **urban movement and visit cluster (Cluster 3)** encompasses digital mapping, tourism, travel, urban points of interest (POS), user activity, tourism, urban functioning, and social media networks. As justified by the keyword network results, urban POS, user activity, and touristic attractions are clustered together. The keyword network highlights data-driven computational analysis methods, urban decision support, and social media networks as two significant nodes connecting the terms. Based on the results, the urban perception cluster has clearer borders with its terms. However, the boundaries between urban activities-density and urban movement-visit are somewhat blurred due to the hotspot and urban functioning terms.

The term *"urban decision support"* has the strongest relationship with city, neighborhood, and place concepts (urban site, area, place, environment), as well as city scale analysis (cities as case studies). The relationship strength between these terms and urban decision support is higher than 30, which indicates a strong relationship. Following this, decision support has strong relationships with methods such as digital mapping, data-driven analysis, sentiment analysis, crowdsourcing, data visualization, spatiotemporal patterns, and clustering. It also has strong relationships with urban research topics, including place identity, data sources, urban functioning, social life, and socioeconomic factors, with a minimum link strength of 15. As the minimum link strength decreases, the relationships expand to encompass the majority of research topics and methods used in the reference studies.

The term “urban decision support” appears 18 times and connects to 40 items with a total link strength of 482. **Figure 8** displays the position of this term in the relationship network. As a result, the term "urban decision support" is primarily strongly related to

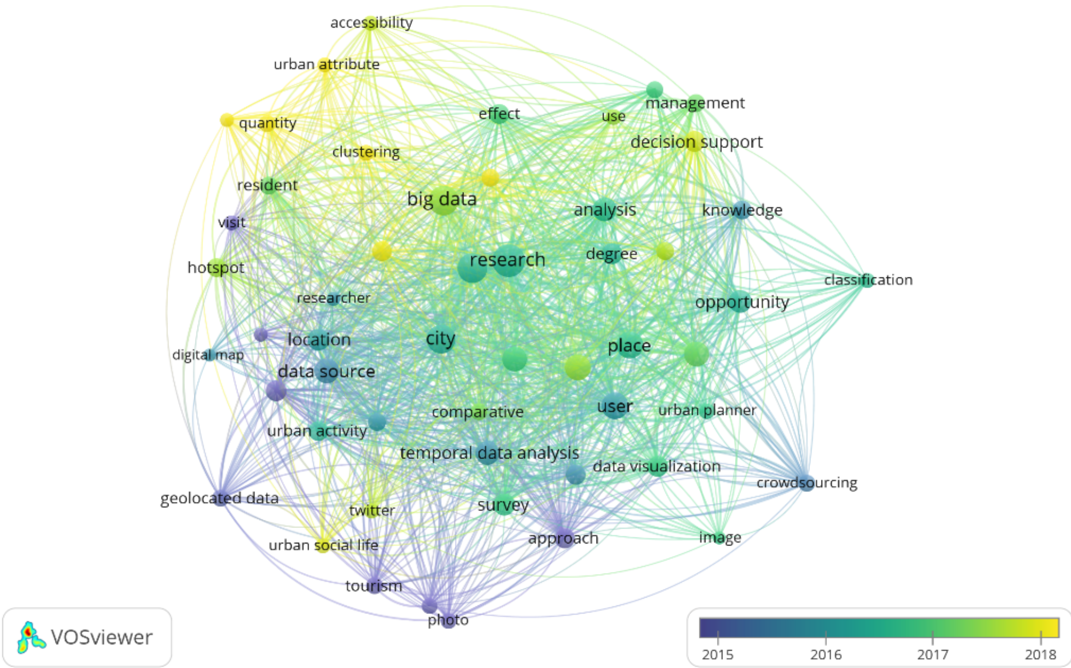
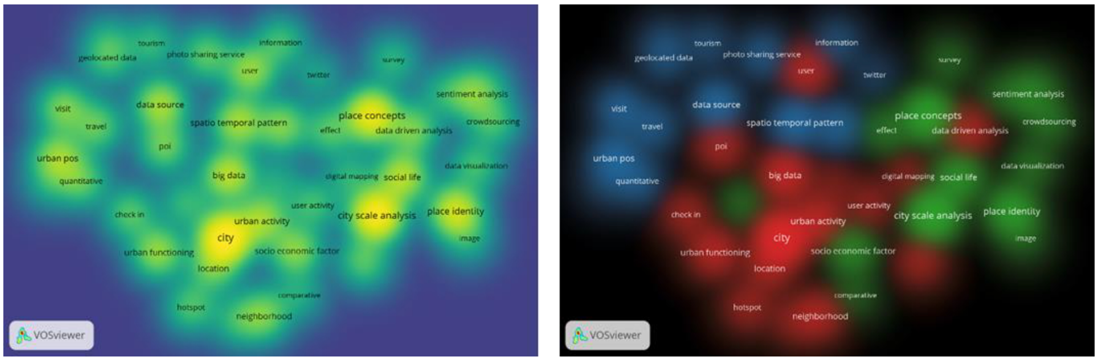


Figure 4. Overlay visualization results of the network.



a b

Figure 5. Density visualization results based on items **(5.a)** and cluster density **(5.b)**.

contextual concepts (city, neighborhood, and place concepts), followed by applied methods (such as data visualization, mapping, data-driven analysis, and spatial statistical techniques) and urban research topics (such as urban activities, urban functioning, user movement, and place identity). In terms of keywords, decision support has strong associations with social media networks, urban social life, spatial statistical techniques, Geographic Information Systems (GIS), urban management, smart city, geolocated data, data-driven computational analysis, urban functioning, and urban activities **(Figure 9).** These associations also indicate a significant relationship between decision support and analysis methods, and their contribution to understanding urban dynamics (urban activity, sentiment, social life, management).

The citation results, as shown in **Figure 10,** indicate that the selected references span the years between 2008 and 2022. Approximately 33% of the references (9) were published up until 2016, while about 66% of the references (18) were published up until 2022. These results demonstrate the growing popularity of big data in urban studies in recent years. The journals in which the reference articles were published have an average of 25 citations, with some outliers. Among them, The European Physical Journal Special Topics, Scientific Reports, IEEE Pervasive Computing, Applied Geography, Computers, Environment and Urban Systems, and Landscape and Urban Planning are the most cited journals, with citations above 100 (as seen in **Table A.3**). According to the documented citation results, the citations of the documents range from 10 to 100 and above. As the citation results show, the

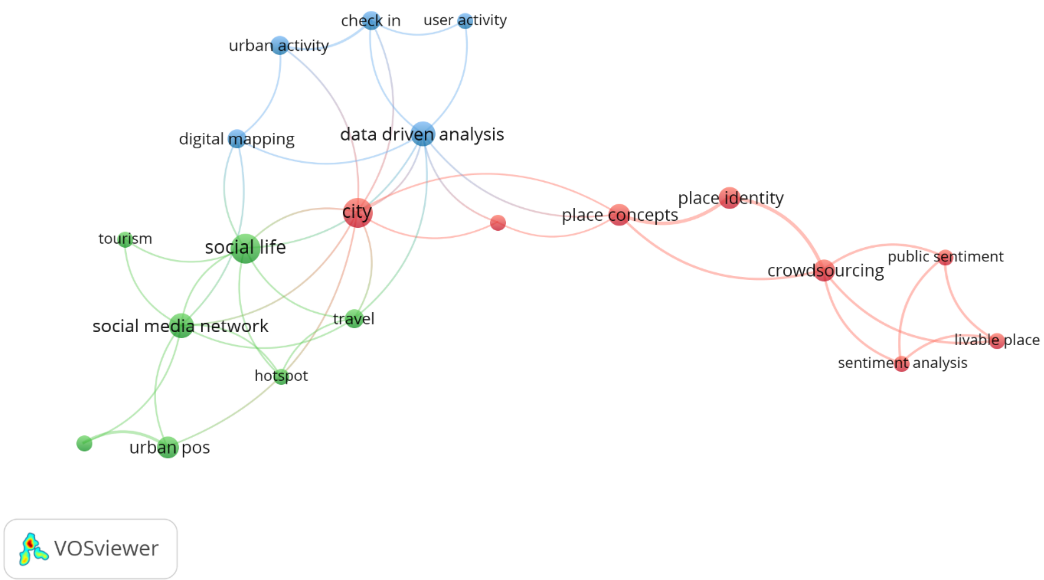


Figure 6. Network visualization of the titles.

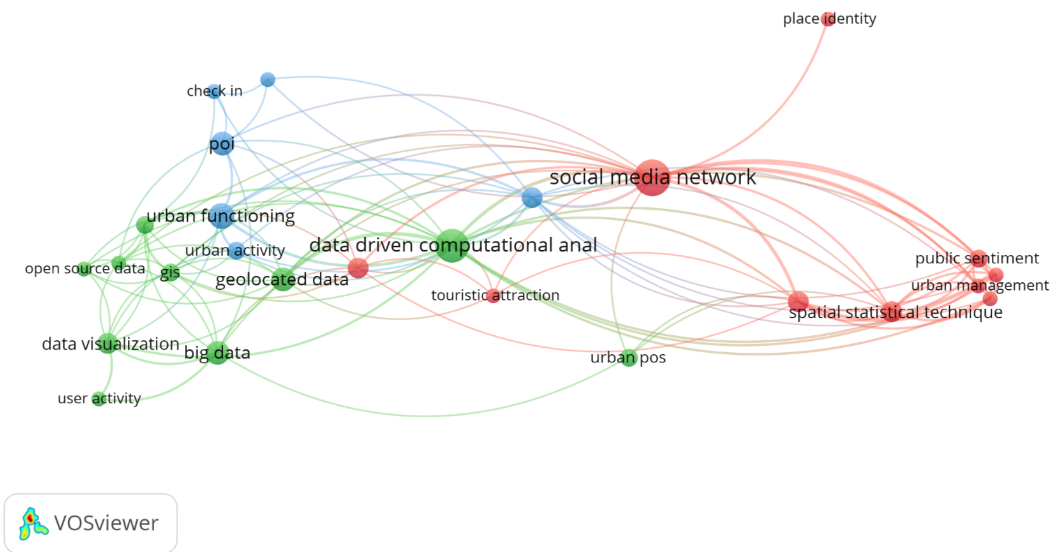


Figure 7. Network visualization of the keywords.

selected articles represent the state of the art research in the big data field. The network results also reveal that the majority of the references are connected to each other in terms of the research topic and applied method.

DISCUSSION

There is a growing trend in using big data to understand urban phenomena and support decision-making. However, urban researchers need to consider the discussions surrounding the drawbacks of big data and data-driven analysis in this data-rich environment. Data-driven analysis of urban systems has faced criticism for oversimplifying the intricate relationship patterns inherent in city systems, drawing parallels to Alexander's "city as tree" concept from the modernist movement (Mattern, 2021). According to Mattern (2021), much like the reduction of complex urban systems to tree-like structures in modernist approaches, data-driven analysis risks simplifying cities into similar structures through data networks, potentially neglecting the inherent complexity and interconnectivity of urban environments. Moreover, other criticisms of data-driven urban analysis are derived from the lack of methodological and theoretical background (Berry, 2011), the absence of sociological, economic, and psychological aspects (Thakuriah et al., 2017), and the missing epistemological links between data-driven modeling and critical urban theory (Thakuriah et al., 2017). In response to these counterarguments, Kitchin (2017) states that data-driven methods change the way

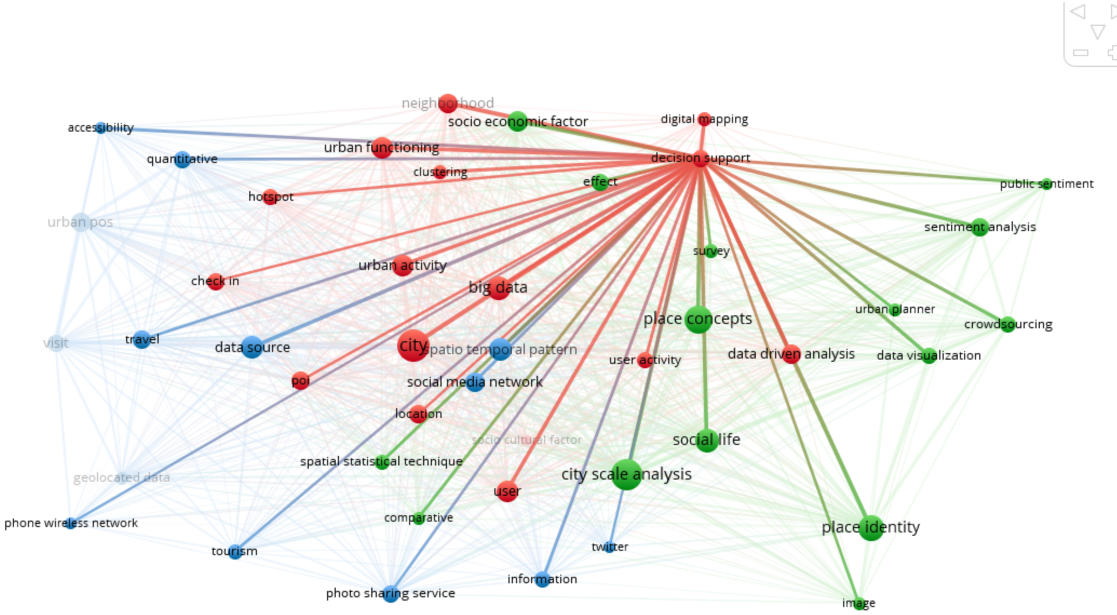


Figure 8. The linkage of the urban decision support with other terms in the abstract.

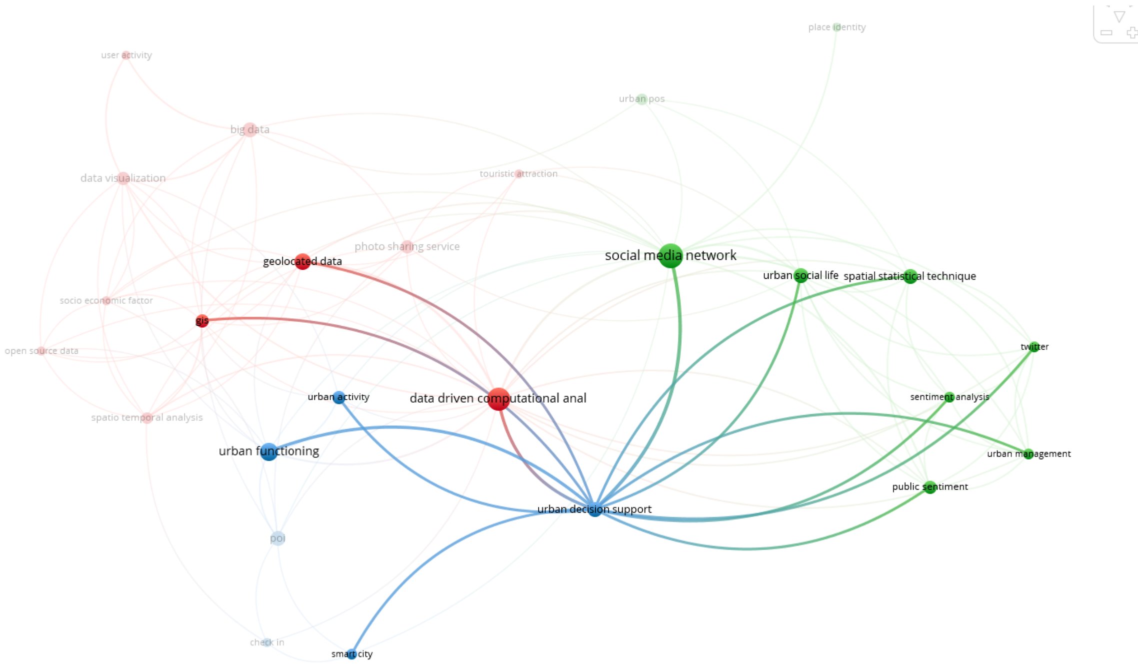
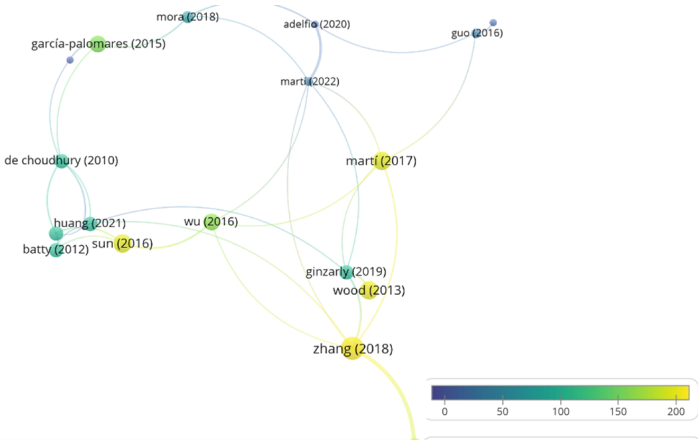


Figure 9. The linkage of the urban decision support with other terms in keywords.

hypotheses are created, shifting from theory to data. Data is processed through algorithms, rather than theories, to discover urban phenomena (Kitchin, 2017).

The drawbacks of big data stem from issues related to representation, ethics, technique, and methodology. In terms of representativeness, ongoing discussions include the adequacy of LBSN sampling in representing collective user patterns, unclear and vague attributes of the sampling, and comparisons with surveys in terms of target coverage. Additionally, there is skepticism about the context, content, ownership of information (Chan, 2015), and blurred lines between commercial and academic research fields (Boyd & Crawford, 2012). Technical drawbacks can be observed in data generation, capturing, processing, and management stages due to the fragmented structure of API raw data (Thakuriah et al., 2017). Different LBSN platforms also have specific technical



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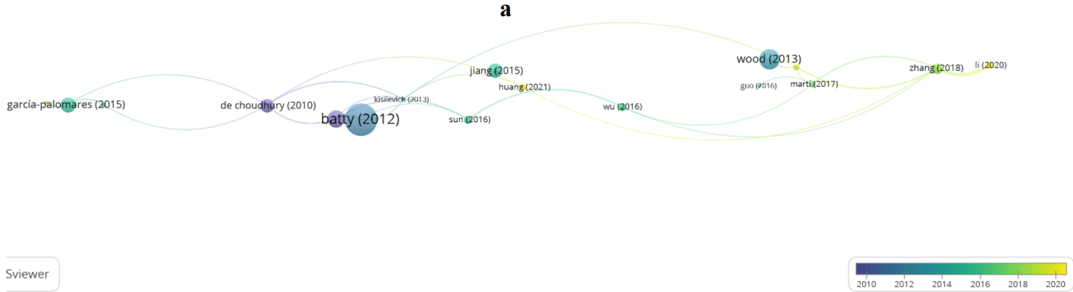

b

Figure 10. Network visualization of the references based on the citations **(Figure 10.a)** and years **(Figure 10.b)**.

drawbacks, such as complexity in requesting and retrieving data, differences in categories and data types, distinct methods used for validation, selection, and interpretation of data, inconsistencies in the retrieval data scale, and user-generated content errors (such as duplications or inaccurate place information, and locative descriptors) (Marti et al., 2019).

The bibliometric mapping network based on the visualization of similarities has the potential to represent the exploration of state-of-the-art research. However, the bibliometric mapping network has challenges in the scope of the study. These challenges are derived from the oversensitivity of the relationship network to minor changes, the existence of multiple correspondence words to describe the same term, and limitations of the tool. This network is very sensitive to minor changes. The network structure changes completely even with minor changes, making it difficult to read the associations and clusters in the network structure each time. The fragile structure creates a limitation. In addition, there are many different definitions to describe the same term. For instance, more than 15 different terms have been used to describe geolocated data. Having so many definitions describing the same term complicates the filtering process. Another difficulty arises from the use of the tool. The fact that the tool only analyzes the text in the abstract prevents the effective analysis of the terms in the articles. In this study, the researcher generates a dictionary to filter the close-meaning terms and creates an appropriate group for them. The filtering process through the dictionary is conducted manually by the researcher. This process is labor and time-intensive and prone to human error. The labor intensiveness of filtering is another limitation of this study.

To overcome these limitations, the filtering process can be furthered with machine learning to provide efficiency. The use of machine learning algorithms in semantics can be employed to construct an automated dictionary in further studies. Further studies could involve reviewing a wider range of literature and exploring different perspectives and approaches to conduct comprehensive research. Additionally, this study can be supported by the collaboration of experts in the field.

CONCLUSION

This paper examines state-of-the-art studies in urban informatics that exploit big data to support urban decisions. In this paper, a qualitative analysis has been conducted to classify the references based on the interrelationships of the terms. The qualitative map results give insight into the association of keywords and the state-of-the-art research in big data, while the quantitative diagram results show the numeric distribution of the keywords in this field. The use of VOSviewer software for the bibliometric analysis of selected studies and the creation of a dictionary to filter close-meaning terms are unique aspects of the study. This study is useful for revealing hot research topics and data analysis methods in the scope of big data in the urban informatics domain. The identification of hot research topics and data analysis methods can help inform the development of decision support systems that use data-driven computational methods, spatial statistical methods, and mapping spatiotemporal patterns of urban phenomena.

In this study, the VOSviewer tool has been used for the literature analysis, which constructs bibliometric networks based on the visualization of similarities (VOS). In this study, VOSviewer contributes to the management, representation, and customization of the relationships and versatility of the analysis. This tool provides the ability to handle large datasets in an efficient way. It represents the complex data network in an easy-to-understand manner. It allows users to customize the visualization of specific relationships or nodes to emphasize the networks. In this study, the researcher customizes the decision support relations with other terms. Moreover, VOSviewer offers to analyze and visualize various types of bibliometric relationships. This study conducts different bibliometric analyses based on the keyword co-occurrence and term co-occurrence in the abstract and titles and citations. These different analysis methods add value to the versatility of this tool.

In this study, the selected reference studies were analyzed with a systematic literature review through the VOSviewer software based on the terms occurring in the title, keywords, and abstracts. In the literature, a systematic literature review was applied by searching the keywords with induction. Unlike the reference studies, the process of the literature study review is based on deduction: from the references to the terms. This literature study aims to map the general trends in big data and urban informatics regarding their intersection with decision support in urban planning and design. It provides an opportunity for further research on the integration of decision support systems in big data studies. In the selected studies, decision support is mostly provided through data-driven computational methods (machine learning and data analytics), spatial statistical methods for clustering and classifications, and mapping the spatiotemporal pattern of urban phenomena. The reference studies support decisions mainly related to urban activities and functioning, user activities (movement), visiting, and urban perception.

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Appendix A: Export results of the analysis in VOSviewer.

Table 6. Terms and occurrences from the abstracts.

Id	Term	Occurrences	Relevance Score
5	city	73	0.2196
6	city scale analysis	65	0.1696
31	research	60	0.0868
26	place concept	55	0.1679
34	social media network	40	0.1393
3	big data	35	0.037
27	place identity	34	0.923
46	urban pos	34	23.111
10	data source	32	0.4046
38	Spatio-temporal analysis	30	0.1099
44	urban functioning	30	0.7392
49	user	29	0.0752
42	urban activity	27	0.1801
21	neighborhood	24	0.2908
51	visit	24	2.582
2	analysis	22	0.4394
28	poi	22	0.2724

Id	Term	Occurrences	Relevance Score
4	Check-in	21	0.4094
20	location	21	0.2213
32	sentiment analysis	21	27.737
41	travel	20	12.811
25	photo sharing service	19	0.2165
30	quantitative	19	17.818
43	urban decision support	19	0.0867
50	user activity	19	0.1875
14	effect	18	0.1261
16	hotspot	18	0.2795
9	crowdsourcing	16	1.796
11	data visualization	16	0.8846
15	geolocated data	15	12.933
19	information	15	0.123
23	opportunity	15	0.4826
36	Socio-economic factor	15	0.5254
40	touristic attraction	15	0.4892

Table 7. The terms and occurrences of the keywords.

Id	Keyword	Occurrences	Total link strength
4	big data	5	8
14	ata driven computational analysis method	10	28
16	data visualization	4	9
19	geolocated data	5	13
20	GIS	3	11
36	photo sharing service	4	9
39	POI	5	6
64	urban social life	4	13

Id	Keyword	Occurrences	Total link strength
41	public sentiment	3	10
45	social media network	12	26
50	patial statistical technique	4	10
51	spatio temporal analysis	3	8
58	urban activity	3	7
60	urban decision support	4	13
61	urban functioning	6	13
63	urban pos	3	4

Table 8. The citation numbers of the references and journals.

Id	Document	Citations	Links
3	Batty (2012)	1038	0
8	Wood (2013)	410	2
27	Girardin (2008)	303	3
9	García-Palomares (2015)	229	2
22	Jiang (2015)	201	0
21	De Choudhury (2010)	182	2
7	Zhang (2018)	124	2
14	Sun (2016)	73	1
1	Wu (2016)	60	1

Id	Document	Citations	Links
6	Martí (2017)	50	1
13	Li (2020)	49	2
25	Huang (2021)	46	0
12	Ginzarly (2019)	43	1
11	Zhou (2016)	37	0
10	Abbasi (2015)	27	2
5	Schlieder (2009)	26	0
17	Mora (2018)	25	1
15	Agryzkov (2017)	21	0

Table 9. The journals citation of the reference articles.

id	source	citations	total link strength		id	source	citations	total link strength
26	The European Physical Journal Special Topics	1042	0		20	Proceedings of The 8th Acm Sigspatial International Workshop On LBSN	27	2
23	Scientific Reports	411	2		24	Spatial Cognition &Amp; Computation	26	0
11	Ieee Pervasive Computing	303	3		25	Sustainability	25	1
4	Applied Geography	229	4		12	International Journal of Geographical Information Science	21	1
8	Computers, Environment and Urban Systems	201	0		10	Geospatial Visualisation	17	1
19	Proceedings of the 21st ACM Conference on Hypertext and Hypermedia	182	2		1	2016 IEEE International Smart Cities Conference (ISC2)	15	0
16	Landscape and Urban Planning	171	2		21	Proceedings of The International AAAI Conference on Web and Social Media	14	0
9	Environment and Planning B: Planning and Design	73	1		18	The 2017 ACM International Symposium on Wearable Computers	9	0
17	Plos One	60	1		2	2016 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (Asonam)	8	0
7	Cities	50	3		5	Applied Spatial Analysis and Policy	6	2
22	Science of the Total Environment	50	2		3	A/Z : ITU Journal of Faculty of Architecture	3	0
13	Journal of Cultural Heritage	44	1		15	Journal of Urban Technology	3	2
6	Cartography and Geographic Information Science	37	0		14	Journal of Planning	0	0

Appendix B: The dictionary to group the related terms.

Label	Replace by		Label	Replace by		Label	Replace by
access	accessibility		Bundang	city scale analysis		amt	data driven computational analysis method
accessible green space	accessibility		China	city scale analysis		computational method	data driven computational analysis method
park accessibility	accessibility		Country	city scale analysis		machine learning	data driven computational analysis method
classification accuracy	accuracy		Dongtan	city scale analysis		calibration	data driven computational analysis method
best accuracy	accuracy		Ilsan	city scale analysis		reality mining	data driven computational analysis method
good agreement	agreement		Korea	city scale analysis		mechanical turk	data driven computational analysis method
new analysis capability	analysis		Rome	city scale analysis		orienteering problem	data driven computational analysis method
detailed analysis	analysis		San Francisco	city scale analysis		page rank algorithms	data driven computational analysis method
social app	app		Seoul	city scale analysis		city computing	data driven computational analysis method
new approach	approach		Songdo	city scale analysis		geographic recommender systems	data driven computational analysis method
interdisciplinary approach	approach		Alicante	city scale analysis		information extraction	data driven computational analysis method
twofold approach	approach		Amsterdam	city scale analysis		web scraping	data driven computational analysis method
available data	available		Athens	city scale analysis		topic modelling	data driven computational analysis method
data	big data		Bamberg	city scale analysis		semantics enrichment	data driven computational analysis method
check	check in		Barcelona	city scale analysis		machine learning algorithms	data driven computational analysis method
park check	check in		Beijing	city scale analysis		new source	data source
Foursquare data	check in		Benchmark	city scale analysis		new type	data source
Weibo	check in		Berlin	city scale analysis		additional source	data source
social media network Foursquare	check in		Cardiff	city scale analysis		additional type	data source
social network Foursquare	check in		Case area	city scale analysis		commercial resource	data source
swarm	check in		Dublin	city scale analysis		latent source	data source
check-ins	check in		Gothenburg	city scale analysis		utilizing resource	data source
check-in	check in		Gothenburg's intermediate city	city scale analysis		variety	data source
Foursquare	check in		Hong Kong	city scale analysis		diversity	data source
swarm app	check in		Istanbul	city scale analysis		variety	data source
large city	city		Italy	city scale analysis		source	data source
major city	city		London	city scale analysis		type	data source
major European city	city		Madrid	city scale analysis		databases	data source
New York City	city		Paris	city scale analysis		reliable proxy	data visualization
cities and towns	city		Pittsburgh	city scale analysis		graphical image	data visualization
classifier increase	classification		Rotterdam	city scale analysis		new visualization method	data visualization
category	classification		Sweden	city scale analysis		visual representation	data visualization
classified model	classification		tri city region	city scale analysis		graph	data visualization
cluster	clustering		Jurong East	city scale analysis		visual programming software	data visualization
clustering analysis	clustering		Singapore	city scale analysis		visualization tool	data visualization
clustering model	clustering		testbed area	city scale analysis		interactive visualization service	data visualization
functional cluster	clustering		case study city	city scale analysis		visualization mode	data visualization
functional clusters	clustering		similar conceptualization	description		representation	data visualization
comparative analysis	comparative		ident	description		graphic	data visualization
comparative study	comparative		partial depiction	description		information visualization	data visualization
distinction	comparative		influence	effect		urban visualization	data visualization
individual difference	comparative		lasting influence	effect		geographic information systems	GIS
difference	comparative		impact	effect		geographic information data source open street map	GIS
comparison	comparative		value	effect		official GIS database	GIS
crowd sourcing marketplace	crowdsourcing		practical implication	effect		GIS	GIS
crowdsourced calibration service	crowdsourcing		show great promise	effect		system	GIS
map	digital mapping		urban center	hotspot		open source	open source data
mapping	digital mapping		city center identification	hotspot		open source data	open source data
mapping third place	digital mapping		higher spatial concentration	hotspot		osm data	open source data
mapping urban data	digital mapping		intermediate city area	hotspot		web server	open source data
maps outdoor physical activity	digital mapping		main hot spot	hotspot		web site	open source data
resulting map	digital mapping		neighborhoods center	hotspot		web sites	open source data
map	digital mapping		spot	hotspot		weblog	open source data
fine grain land use mapping	digital mapping		tourist hot spot	hotspot		Airbnb	open source data
fine grain mapping	digital mapping		center identification	hotspot		new opportunity	opportunity
digital map	digital mapping		city center	hotspot		great opportunity	opportunity
digital recording	digital mapping		new technology	ICT		possibility	opportunity
latitude longitude	geolocated data		communication	ICT		advantage	opportunity
analyzing people's geo	geolocated data		technology	ICT		cell phone network data	phone wireless network
available geotagged check	geolocated data		leverage voluntary local knowledge	knowledge		social network	phone wireless network
footprint	geolocated data		potential bias	limitation		mobile phone network	phone wireless network
geo temporal breadcrumb	geolocated data		limited accuracy	limitation		mobile phone user	phone wireless network
geolocated information	geolocated data		limited agreement	limitation		Telecom Italia mobile	phone wireless network

geolocated social media data	geolocated data		geo	location		wireless network event	phone wireless network
georeferenced photo	geolocated data		accurate location	location		mobile phone	phone wireless network
geotagged photograph	geolocated data		reliable measure	measure		wireless network	phone wireless network
geotagged social media data	geolocated data		novel method	method		photograph	photo sharing service
location information	geolocated data		methodological technique	method		photo stream	photo sharing service
locational log	geolocated data		new way	method		photographer	photo sharing service
volunteered geographic information	geolocated data		conventional method	method		photography	photo sharing service
locational data	geolocated data		new method	method		residents photograph	photo sharing service
digital footprinting	geolocated data		overall methodology	method		Instagrammability	photo sharing service
pervasive user-generated content	geolocated data		methodology	method		Instagram	photo sharing service
user-related spatio temporal data	geolocated data		way	method		Flickr	photo sharing service
geo-tags	geolocated data		administrative boundary	neighborhood		Flickr data	photo sharing service
geospatial semantics	geolocated data		administrative neighborhoods	neighborhood		Instagram	photo sharing service
location-based services	geolocated data		administrative subdivision	neighborhood		Instagramability	photo sharing service
location-based social networks	geolocated data		city partition	neighborhood		Panoramio	photo sharing service
social tagging	geolocated data		city s administrative neighborhoods	neighborhood		web site Flickr	photo sharing service
geospatial data	geolocated data		intermediate city neighborhood	neighborhood		photo-sharing services	photo sharing service
location-based social media	geolocated data		Kadiköy municipal boundary	neighborhood		geotagged photo collections	photo sharing service
volunteered geographic information (vgi)	geolocated data		neighborhood boundaries	neighborhood		urban location	place concept
volunteered geographic information	geolocated data		neighborhood boundary	neighborhood		city place	place concept
volunteered geographic information	geolocated data		polynuclear neighborhood structure	neighborhood		place concepts	place concept
data sources Google Places	Google Places		precise boundary	neighborhood		site	place concept
Google Places data	Google Places		boundary	neighborhood		affluent area	place concept
Google Places social networks	Google Places		neighborhood	neighborhood		area	place concept
overall image	image		site observation	observation		preferred urban space	place concept
single image	image		site observation	observation		characterized area	place concept
image collection	image		direct observation	observation		third	place concept
prior information	information		Bing maps	open source data		third place	place concept

skilled interaction	interaction		online real estate listing	open source data		third places	place concept
urban China	place concept		city project	research		higher ethnic diversity	socio cultural factor
environment	place concept		study	research		worker	socio cultural factor
urban environment	place concept		paper	research		age group	socio cultural factor
urban space	place concept		article	research		digital age	socio cultural factor
place	place concept		work	research		gender	socio cultural factor
crowdsourced cognitive map	place identity		further research	research		cultural ecosystem services	socio cultural factor
public image	place identity		larger research project	research		housing	socio economic factor
city image	place identity		scientist	researcher		socio economic statistic	socio economic factor
cognitive mapping	place identity		large scale	scale		socio economic statistic	socio economic factor
collective identity	place identity		study scale	scale		city s business distribution	socio economic factor
collective place identity	place identity		3d sentiment map	sentiment analysis		economic trend	socio economic factor
conventional cognitive mapping method	place identity		geo sentiment analysis mechanism	sentiment analysis		livehoods project	socio economic factor
identity	place identity		geo sentiment analysis service	sentiment analysis		lower income level	socio economic factor
imageable city	place identity		2d sentiment dashboard	sentiment analysis		neighborhoods economic activity	socio economic factor
node	place identity		sentiment analysis process	sentiment analysis		e commerce	socio economic factor
people's cognitive perception	place identity		sentiment analysis mechanism	sentiment analysis		economy	socio economic factor
urban identity	place identity		sentiment analysis service	sentiment analysis		economic activity	socio economic factor
urban identity a crowd	place identity		social sentiment analysis	sentiment analysis		costs	socio economic factor
edge	place identity		social sentiment analysis engine	sentiment analysis		housing prices	socio economic factor
architectural landmark	place identity		social sentiment analysis feature	sentiment analysis		art research technique	spatial statistical technique
imageability	place identity		training sentiment classifier	sentiment analysis		kernel density estimation	spatial statistical technique
imagery	place identity		smart cities	smart city		multiple linear regression	spatial statistical technique
Kevin Lynch	place identity		social media	social media network		possible correlation	spatial statistical technique
public image	place identity		online social media website	social media network		strong spatial relationship	spatial statistical technique
points of interest	poi		social medium	social media network		weighted regression	spatial statistical technique
pois	poi		social media text data	social media network		statistic	spatial statistical technique
interests	poi		locative social media network	social media network		technique	spatial statistical technique
main tourist attraction	poi		locative social medium	social media network		pattern classification	spatial statistical technique
major attraction	poi		popular social media platform	social media network		dbscan	spatial statistical technique

poi graph	poi		smd	social media network		Grivan-Newman	spatial statistical technique
points	poi		social network data	social media network		local getis-ord	spatial statistical technique
tourist attraction	poi		social networking data	social media network		regression models	spatial statistical technique
interest	poi		text	social media network		greater dispersion	spatio-temporal analysis
attraction	poi		text message	social media network		coarse class granularity	spatio-temporal analysis
question	problem		utilizing social media	social media network		rich spatial temporal information	spatio-temporal analysis
issue	problem		geotagged social network data	social media network		peoples spatiotemporal activity pattern	spatio-temporal analysis
laborious task	problem		geotagged social network message	social media network		spatial choice	spatio-temporal analysis
research question	problem		social media data	social media network		spatial definition	spatio-temporal analysis
public sentiments	public sentiment		social networks	social media network		spatial heterogeneity	spatio-temporal analysis
aggregate record	quantitative		social media	social media network		spatial pattern	spatio-temporal analysis
increased number	quantitative		social network analysis	social media network		Spatio-temporal city characteristic	spatio-temporal analysis
larger number	quantitative		social media analytics	social media network		Spatio-temporal phenomena	spatio-temporal analysis
quantitative ing park use	quantitative		diverse socio cultural factor	socio cultural factor		spatio-temporal analysis	spatio-temporal analysis
quantitative comparison	quantitative		higher ethnic diversity	socio cultural factor		spatial analysis	spatio-temporal analysis
quantitative understanding	quantitative		socio cultural factor	socio cultural factor		day	spatio-temporal analysis
quantitative	quantitative		traditional social character	socio cultural factor		year	spatio-temporal analysis
number	quantitative		diverse socio cultural factor	socio cultural factor		date data	spatio-temporal analysis
specifying time	spatio-temporal analysis		activity intensity	urban activity		public administration	urban management
strong spatial concentration	spatio-temporal analysis		activity pattern	urban activity		designers planners	urban management
concentration	spatio-temporal analysis		city exhibits urban activity	urban activity		city planner	urban management
temporal coverage	spatio-temporal analysis		intermediate city s urban activity area	urban activity		relevant plaza	urban pos
time	spatio-temporal analysis		urban activity	urban activity		successful plaza	urban pos
time series analysis	spatio-temporal analysis		urban function	urban activity		successful public space	urban pos
timely way	spatio-temporal analysis		urban economic activities	urban activity		successful urban plaza	urban pos
time	spatio-temporal analysis		urban activities	urban activity		square	urban pos
extensive survey	survey		appropriate decision making	urban decision support		recreational site	urban pos
questionnaire response	survey		insight	urban decision support		recreational area	urban pos
surveys interview	survey		ground truth	urban decision support		leisure	urban pos

visitor survey	survey		provision	urban decision support		urban park	urban pos
interview	survey		strong support	urban decision support		cultural relics park	urban pos
subject	topic		urban decision making	urban decision support		large urban park	urban pos
historic city center	touristic attraction		urban design decision	urban decision support		national park	urban pos
cultural heritage	touristic attraction		politic	urban decision support		neighborhood park	urban pos
historic urban landscape	touristic attraction		decision	urban decision support		park context	urban pos
popular bus tour	touristic attraction		decision making	urban decision support		park location	urban pos
tourist	touristic attraction		policy	urban decision support		park size	urban pos
tourism geography	touristic attraction		evidence	urban decision support		park typology	urban pos
uncovering tourist	touristic attraction		urban design decision support	urban decision support		park user	urban pos
touristic attractions	touristic attraction		urban planning	urban decision support		park usage	urban pos
trail	track		dynamic urban area	urban dynamic		plaza	urban pos
destination constraint	travel		dynamics	urban dynamic		public space	urban pos
bus stop	travel		human dynamic	urban dynamic		recreational demand	urban pos
bus station	travel		fine grain land use taxonomy	urban functioning		urban greenspace	urban pos
high quality travel	travel		coarse grain authoritative data	urban functioning		park attributes	urban pos
human travel	travel		urban data	urban functioning		park	urban pos
intra city travel	travel		residential area	urban functioning		services comprise	urban service
vacation planning	travel		local resident	urban functioning		service	urban service
transport	travel		clear topology	urban functioning		everyday life	urban social life
public transportation	travel		better understanding	urban functioning		life	urban social life
travel itinerary	travel		understand	urban functioning		social activity	urban social life
transit time	travel		land use	urban functioning		social breadcrumbs	urban social life
transportation need	travel		character	urban functioning		social dynamic	urban social life
travel itineraries	travel		factor	urban functioning		social life	urban social life
travel web site	travel		characteristic	urban functioning		life habit	urban social life
travelers origin	travel		condition	urban functioning		social spaces	urban social life
Twitterability	Twitter		state	urban functioning		everyday landscape	urban social life
Twitter	Twitter		street networks	urban functioning		livable places	urban social life
activity	urban activity		city characteristics	urban functioning		big project livable places	urban social life
function	urban activity		gentrification	urban functioning		individual user	user
land use	urban activity		urban functions	urban functioning		person	user
restaurant	urban activity		local authority	urban management		humans	user
active print	urban activity		functional organization	urban management		greater cross movement	user activity

active urban area	urban activity		city government	urban management		urban sports movement	user activity
activity area	urban activity		place design	urban management		outdoor physical activity	user activity
fitness applications	user activity		passive track	user activity		human mobility	user activity
sports activity	user activity		similar trait	user activity		park visit	visit
personal fitness data	user activity		usage	user activity		approximate visitation rate	visit
run	user activity		human activity	user activity		empirical visitation rate	visit
urban jogger	user activity		human behavior	user activity		entrance	visit
path	user activity		user activity patterns	user activity		entrance fee	visit
digital trace	user activity		people's behavior	user activity		higher visitation rate	visit
visitation rate	visit		visitor	visit		entry	visit
visitor attraction	visit						

DESCRIPTION

Journal of Technology in Architecture Design and Planning (JTADP) is an open-access, peer-reviewed and scholarly journal published biannually in May and November. The journal is the official online-only publication of Istanbul University Faculty of Architecture. JTADP aims to contribute to the knowledge in the fields of architecture, design and planning with a focus on technology dimension. The publication language of the journal is English. Articles submitted to JTADP are subject to a double-blind peer-review evaluation system. The journal targets national and international audience. Target audience of the journal includes academicians, researchers, professionals, students, and related professional and academic bodies and institutions.

Processing and publication are free of charge with the journal. There is no article processing charges or submission fees for any submitted or accepted articles.

AIM AND SCOPE

Journal of Technology in Architecture Design and Planning (JTADP) aims to contribute to the knowledge in the fields of architecture, design and planning with a focus on technology dimension. It is an open-access, peer-reviewed and scholarly journal published biannually in May and November. In order to expand the boundaries of knowledge in these fields and provide an international forum for the interchange of information and current issues from around the world, JTADP publishes double blind refereed articles on practice and progress regarding the fields; these include research articles, review articles, reviews of projects and case studies. Subjects covered by JTADP include, but are not limited to: Architectural engineering, design engineering, urban engineering.

Technology is defined as a process that covers the transformation and use of basic and applied sciences' data into production within creative processes and the analysis of their social effects. Hence, technology naturally constitutes the essence of architecture, design and planning actions.

The fact that technology takes place as a process in all kinds of design activities emphasizes the organic and inseparable unity of the three aforementioned fields and their sub-titles with technology. Technology, and therefore architecture, design and planning, is a combination of creativity and intelligence with science, art, engineering, economics and social studies in order to increase the quality of human life. The point that should be noted here is that technology is not only related to science and engineering, but also a reflection of fields such as art, sociology, psychology and economics.

Based on the fact that the technology dimension is not adequately addressed in scientific publications in the fields of architecture, design and planning, it has been decided that JTADP will focus on these issues. Moreover, JTADP aims to explore the interface between design, architecture, planning and their practical applications.

EDITORIAL POLICIES AND PEER REVIEW PROCESS

Publication Policy

The journal is committed to upholding the highest standards of publication ethics and pays regard to Principles of Transparency and Best Practice in Scholarly Publishing published by the Committee on Publication Ethics (COPE), the Directory of Open Access Journals (DOAJ), the Open Access Scholarly Publishers Association (OASPA), and the World Association of Medical Editors (WAME) on https://publicationethics.org/resources/guidelines-new/principles-transparency-and-best-practice-scholarly-publishing

The subjects covered in the manuscripts submitted to the Journal for publication must be in accordance with the aim and scope of the Journal. Only those manuscripts approved by every individual author and that were not published before in or sent to another journal, are accepted for evaluation.

Changing the name of an author (omission, addition or order) in papers submitted to the Journal requires written permission of all declared authors.

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Journal of Technology in Architecture Design and Planning (JTADP) adheres to the highest standards in research ethics and follows the principles of international research ethics as defined below. The authors are responsible for the compliance of the manuscripts with the ethical rules.

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- The research team and participants should be fully informed about the aim, methods, possible uses and requirements of the research and risks of participation in research.

- The confidentiality of the information provided by the research participants and the confidentiality of the respondents should be ensured. The research should be designed to protect the autonomy and dignity of the participants.

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- Any possible harm to participants must be avoided. The research should be planned in such a way that the participants are not at risk.

- The independence of research must be clear; and any conflict of interest or must be disclosed.

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- If the study is to be carried out in any institution or organization, approval must be obtained from this institution or organization.

- In studies with human subject, it must be noted in the method’s section of the manuscript that the informed consent of the participants and ethics committee approval from the institution where the study has been conducted have been obtained.

Author’s Responsibilities

It is authors’ responsibility to ensure that the article is in accordance with scientific and ethical standards and rules. And authors must ensure that submitted work is original. They must certify that the manuscript has not previously been published elsewhere or is not currently being considered for publication elsewhere, in any language. Applicable copyright laws and conventions must be followed. Copyright material (e.g. tables, figures or extensive quotations) must be reproduced only with appropriate permission and acknowledgement. Any work or words of other authors, contributors, or sources must be appropriately credited and referenced.

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Editor-in-Chief evaluates manuscripts for their scientific content without regard to ethnic origin, gender, sexual orientation, citizenship, religious belief or political philosophy of the authors. He/She provides a fair double-blind peer review of the submitted articles for publication and ensures that all the information related to submitted manuscripts is kept as confidential before publishing.

Editor-in-Chief is responsible for the contents and overall quality of the publication. He/She must publish errata pages or make corrections when needed.

Editor-in-Chief does not allow any conflicts of interest between the authors, editors and reviewers. Only he has the full authority to assign a reviewer and is responsible for final decision for publication of the manuscripts in the Journal.

Reviewers must have no conflict of interest with respect to the research, the authors and/or the research funders. Their judgments must be objective.

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Peer Review Policies

Only those manuscripts approved by its every individual author and that were not published before in or sent to another journal, are accepted for evaluation.

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The editor hands over the papers matching the formal rules to at least two national/international referees for double-blind peer review evaluation and gives green light for publication upon modification by the authors in accordance with the referees' claims.

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Reviewers' judgments must be objective. Reviewers' comments on the following aspects are expected while conducting the review.

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- Is the problem significant and concisely stated?
- Are the methods described comprehensively?
- Are the interpretations and consclusions justified by the results?
- Is adequate references made to other Works in the field?
- Is the language acceptable?

Reviewers must ensure that all the information related to submitted manuscripts is kept as confidential and must report to the editor if they are aware of copyright infringement and plagiarism on the author's side.

A reviewer who feels unqualified to review the topic of a manuscript or knows that its prompt review will be impossible should notify the editor and excuse himself from the review process.

The editor informs the reviewers that the manuscripts are confidential information and that this is a privileged interaction. The reviewers and editorial board cannot discuss the manuscripts with other persons. The anonymity of the referees is important.

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