RCL — Revista de Comunicação e Linguagens *Journal of Communication and Languages* N.60 (2024) ISSN 2183-7198

Data-Driven urban representations: Systems thinking as an operational challenge for a deep reading of contemporary cities

Representações urbanas alicerçadas em dados: o pensamento sistémico como desafio operacional para uma leitura profunda das cidades contemporâneas

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Abstract

Contemporary urban conditions, where different agencies are associated through various spatial confrontations, are redefined as a system with all its components; socioeconomic, biological, geographical, ecological, and experiential. Incorporating these coexistences in the definition of urban conditions necessitates a multi-focal rendering of the associations and a speculative practice of a new methodological approach.

This article considers the use of data-driven urban representations for achieving a 'systems thinking' approach as a new methodology to research the pluralities, contradictions, degradations, and climatic challenges of contemporary cities. In this respect, the experienced data avalanche and interaction with the large scale of bytes used for data-driven practices can be considered as a challenging transformation that proposes deep readings of cities and hence can be used in practising a 'systems thinking' approach. Mapping the information and producing data-driven urban representations can be considered a challenge in defining the systems thinking approach and responding to the transformations, definitions, and conditions of contemporary cities. This new method of engagement with data-driven practices cultivates an architectural transformation by sourcing,

inspiring, and informing the architectural design processes for understanding the notion of resilient cities. The article speculates on the potential of systems thinking initiated by data visualisations in producing deep readings of contemporary cities and its use as a methodological approach in architectural design education. Massive amounts of data collected, studied, and represented at different scales expose the city's visible and invisible features and enable alternative readings and representations of the city. Various data sets translated into different forms of mapping strategies are believed to inform a series of discussions on the capacities of the city to reinvent itself constantly, correlate innovation at many scales, and therefore, bring forth alternative frameworks for urban innovability in the digital transition era.

Keywords

urban representation | data visualisation| system thinking | digital media | architectural research

Resumo

As condições urbanas contemporâneas, onde diferentes agências se encontram associadas através de vários confrontos espaciais, estão a ser redefinidas como um sistema com todas as suas componentes: socioeconômico, biológico, geográfico, ecológico e experiencial. Incorporar estas coexistências na definição de condições urbanas exige uma representação multifocal das associações e uma prática especulativa de uma nova abordagem metodológica.

Este artigo pondera no uso de representações urbanas alicerçadas em dados para actualizar uma aproximação assente num 'pensamento sistémico' enquanto nova metodologia para investigar as pluralidades, contradições, degradações e desafios climáticos das cidades contemporâneas. A este respeito, a avalanche de dados e a interacção com a com a elevada escala de bytes utilizados para práticas fomentadas por dados podem ser consideradas como uma transformação desafiadora que propõe leituras aprofundadas de cidades e, consequentemente, podem ser usadas na prática de uma abordagem por meio de um 'pensamento sistémico'. O mapear da informação e a produção de representações urbanas assentes em dados podem ser consideradas como um desafio na definição da abordagem de um pensamento sistémico e na resposta às transformações, definições e condições das cidades contemporâneas. Este novo método de envolvimento com práticas baseadas em dados cultiva uma transformação arquitectural ao fundar, inspirar e informar os processos de design arquitectónico em vista de compreender a noção de cidades resilientes. O artigo especula sobre o potencial de um pensamento sistémico iniciado pelas visualizações de dados na produção de leituras aprofundadas das cidades contemporâneas e o seu uso enquanto uma aproximação metodológica na educação do design arquitectónico. Quantidades massivas de dados recolhidos, estudados e representados em diferentes escalas expõem os traços visíveis e invisíveis das cidades e permitem leituras e representações alternativas da cidade. Acredita-se que vários data sets traduzidos para diferentes estratégias de mapeamento desdobram-se numa série de discussões sobre as capacidades da cidade em se reinventar constantemente, correlacionando inovação em múltiplas escalas e, consequentemente, desvelando enquadramentos alternativos para a inovabilidade urbana na era da transição digital.

Palavras-chave

representações urbanas | visualização de dados | pensamento sistémico |media digitais | investigação arquitectónica

1. Introduction

The physical and conceptual transformations that the cities have undergone in the last decades as a consequence of environmental degradation, ecological destruction, and anthropogenic climate changes transformed the urban conditions and their representations in a significant way, a fact that impels us to re-conceptualise the city as a more complex, saturated, and open structure. The urban condition(s) of the contemporary city, where different agencies interact through various spatial confrontations, can be defined as an ecosystem with all its components; socioeconomic, biological, geographical, ecological, and experiential. At the juncture of these dimensions, architecture as a discipline is expected to define resilient approaches for unprecedented levels of urbanisation, climatic degradation, and an ever-accelerating technological environment, challenging the norms and expectations with an interdisciplinary perspective (Easterling 2014).

Addressing these redefined urban conditions requires a comprehensive perspective to grasp the wide array of connections and interdependencies, prompting a reevaluation of assumptions, approaches, and methodologies in disciplines like urban design, architecture, engineering, politics, and others. To incorporate all vibrant agents in the definition of urban conditions, today's architectural research needs a multi-focal rendering of these discreet associations that are intricate parts of the economic, political, and ecological relations of 21st-century cities. Since research in the field of architecture cannot be done independently of the current conditions of cities, any attempt to respond to the complex, unpredictable, and dynamic organisations of contemporary urban conditions demands a series of zoom-in and zoom-out operations. This new type of research holds the potential to oscillate between different perspectives and envisage the larger dynamics of the city. It is only through such a holistic approach that one can arrive at a complex matrix, which is pervasive enough to encompass new networks, constellations, and occurrences and hence provide insights into the emergent conditions while bearing in mind the roles played by various agents (such as human, non-human, international, intergovernmental, and nongovernmental).

The increased complexity of the city and the emergent relationships between the city, citizens, and society are also affected by the radical shifts in information and communication technologies, for capabilities of gathering, storing, and processing information are increasingly common ground. Computers and their variances have been embedded in all aspects of our lives in recent years. Accordingly, urban environments are occupied with data collectors, processors, and archives, where a huge amount of data is made accessible and visible to society and designers. With these abilities, the contemporary city gains the capacity to store and share its data through various layers and media. Massive amounts of data are stored, processed and conveyed continuously since cities generate new and fresh data at increasing speed and variety. This condition inevitably influences how we approach digital humanities to understand and reflect on contemporary urban culture.

The amount of available and operative data causes a dramatic shift in how humans understand, define, and visualise cities. However, changes defined through the use of data are not only at a city scale and affect all sections of life, as data became the 'de facto standard through which the world is ordered and understood' (Boyd and Crawford 2012). The current tendency to understand the world (cities, science, business, etc.) and humans through data -mainly through the big and incomprehensible amount of data- requires an extension of human perceptive and cognitive capabilities, which results in significant changes in society. Although the increasing tendency to render the world through numbers is an ever-present debate (Scott 1998), the scale of current data sets defines a radical change in society and should be handled with a different mindset in the scope of the digital humanities. The challenges of handling complex, big data make it urgent to adopt a new mindset and a more effective approach since conventional methods will not be enough to deal with the multidimensionality of large data sets.

Gathering, processing, and visualising the multidimensional and massive amounts of data through contemporary tools and models enables focusing on what was not visible in the representation of the city. This search for working with the unacknowledged features of the city and introducing them as new layers of their multidimensional readings are defined through technological advances (Amoroso 2015). However, such an approach to reading the city with its visible and invisible features needs alternative methods and forms of representation. Since they are expected not only to document the existing but also to bring the invisible information to the forefront and make it visible, they should be open to unpredicted readings and interpretations (Amoroso 2010). Technological advances and new modes of visualisation provide alternative readings and should be embraced in understanding old and recent city conditions.

Architects and architectural students are inevitably affected by this change as their subject of interest is always related to the city. In the wake of the urgency to use alternative ways of collecting, processing, and conveying information and its visualisation, data-driven urban representations are a significant method, revealing the multidimensional aspects of cities, regardless of whether they are visible or invisible. This also alters conventional representational practices, particularly in architecture. The reconceptualisation of the notion of representation by large amounts of data can be seen as something that transforms architectural *praxis* and a way to address information that vastly exceeds the limits of human cognition and perception. Therefore, this article will focus on data-driven practices used to record and define new possibilities for urban conditions. It further elaborates on the implications of the '*systems thinking*' approach and data-driven urban representations for architectural education and communication and for questioning contemporary cities.

RCL — Revista de Comunicação e Linguagens *Journal of Communication and Languages* N.60 (2024) ISSN 2183-7198

2. Systems Thinking — A Methodological Approach for Urban Complexity

This conscious search for producing deep readings of cities through the integration of diverse agencies, multiple perspectives, and emergent conditions calls for the use of new tools, methodologies, and media in research and design processes. Systems thinking -by welcoming complexity and multiplicity- addresses the use of continuous and massive data sources and offers a conceptual and methodological approach to reading the complexity of contemporary cities. While discussing the possibilities offered by the methodology of systems thinking, this article also aims to examine how new representation practices triggered by the current digital transformation, contribute to handling urban data. In doing so, it discusses the outcomes of an experimental urban research process conducted in architecture design studios, where systems thinking is applied for two consecutive years with the help of data-driven representations.

Systems thinking is an approach that aims to understand the overall system together with other related systems and their parts. It is a terminology that has roots in the field of management, as Peter Senge discussed in detail as the *Fifth Discipline*. He defines systems thinking as a framework for creating a learning organisation, where parts interact with each other and create complexity and systematicity. According to Peter Senge, systems thinking is "a framework for seeing interrelationships rather than things, for seeing patterns rather than static snapshots. It is a set of general principles spanning fields as diverse as physical and social sciences, engineering, and management" (Senge 2006) In Senge's approach, systems thinking is instrumental for seeing wholes by focusing on inter-relationships rather than things, and patterns rather than static 'snapshots'. (Senge 2006) It defines a cohesive system, where different parts, at different scales and with different properties are interrelated with each other to define a complex whole. Due to this perspective, systems thinking can be regarded as an architectural research and even design methodology for studying complex structures. The adaptation of this methodology, especially to the study of contemporary urban conditions is seen as a meaningful tool for understanding and engaging with the rapidly changing and evolving cities.

Providing an in-depth understanding of complex conditions, systems thinking depends on the ability to represent and assess dynamic complexity, acknowledge feedback processes, identify relationships rather than outputs, and recognise nonlinearity and irregularity. (Sweeney and Sterman 2000) It is concerned with recognising a dynamic 'behavior that arises from the interaction of a system's agents over time' that leads to various levels of complexity. (Sweeney and Sterman 2000) Welcoming collaboration and input through the processes of the operative mapping of data, systems thinking aims to increase the delivery of complexity and hence focuses on defining a complex whole. The concept of 'wholeness' implies that a system is made up of various sub-systems. According to Russell Ackoff, a system is not the sum of the behaviour of its parts;

it is a product of their interactions. (Ackoff 2015) This definition of wholeness enables us to understand how complex organisations operate in a dynamic and interconnected way since the focus is on the interaction between elements and not on their discreteness and individuality. Zooming in and out to see different relations and interactions, the concept of wholeness also prioritises the dynamics of the system rather than the outputs. Accordingly, systems thinking requires us to focus on the whole system with a holistic view and consider each action in the context of the broader system in which it is embedded. (Cavaleri and Sterman 1997) To conceptualise the system as a 'whole' composed of various complex systems at different scales and compositions also allows for the redefinition of each sub-system in relation to others. This continuous feedback loop within the system implies the notion of emergence.

Since urban and architectural development strategies are expected to deal with diversity, manage technological challenges, encourage sustainable development, react to climate change, environmental degradation, and ecological destruction, etc., urban and architectural research and development strategies are expected to define a holistic approach that embraces tolerance and complexity in the digital era. Drawing on data-driven representations to arrive at systems thinking to read, design, and structure contemporary urban conditions helps architects and students address the pluralities, contradictions, degradations, complexities, and challenges of 21st-century cities. By adopting this methodology, architectural research is able to take into account broader and long-term implications, focus on interrelationships rather than cause-and-effect relationships, and provide a multi-focal rendering of relations.

However, the structure and the concept of systems thinking need an in-depth, interdisciplinary approach that recognises change as being constant (Weisz 2018). To acquire, interpret, and use the ever-changing data of a city, the research may incorporate qualitative and quantitative data. Data visualisations, in particular, which allow for different and diverse pieces of information and data to be displayed simultaneously can be used alongside the systems thinking methodology. The digitalisation of the medium enables a holistic ground for research, where fragmented or disconnected information related to the city can be seen together. Viewed as a new challenge for the systems thinking approach, these multilayered and multidimensional representations of complex data can represent the ever-changing relations, and ever-expanding data of the city with all its components and transform how we understand, define, and visualise cities.

Therefore, this approach produces a deeper analysis of the city at various scales and perspectives, where several systems interact to define a complex whole, thus providing advantages for embracing complexity in architectural research. The examples chosen for discussion within this framework are from an architectural research studio in the Department of Architecture at TED University. These examples aim to reveal how systems thinking has been adapted to the context of architectural research as a method for reading and discussing the city and how data-driven urban representations are a significant tool in this endeavour.

RCL — Revista de Comunicação e Linguagens *Journal of Communication and Languages* N.60 (2024) ISSN 2183-7198

The discussion on the systems thinking approach is presented as a research ground that is different from the accustomed and conventional methods of urban studies and a method which increases the potential of using digital media and representations. The article also includes the outcome of a survey conducted with the students who went through this experience and a discussion of examples produced in the design studio. As will be seen in the detailed discussion of the examples, the systems thinking approach, which is usually operationalized in the first semester of the 4th grade, helps students develop a series of readings and interpretations about the whole city based on the region they examine rather than focusing only on a particular site. Therefore, the assigned areas for each semester require a particular inquiry, *i.e.*, a search for solutions and design approaches at an urban scale rather than at an architectural, with a focus on problematic areas within the city.

3. Representations of Urban Conditions

Two major port cities in different geographies were studied in two different years: Beirut in Lebanon and Samsun in Turkey. Even though the cities are different, the studio's main objective remained consistent in its pursuit of addressing the spatial, material, and experiential dispositions along the encounters of water with the land/city and in developing adaptive, solitary and resilient strategies for the particular urban context. Most of the examples to be discussed here, considered operative data-driven mappings, benefited from the research conducted in the first 3-5 weeks of the design studio practices. Each student group focused on a different aspect as the foundation of their research. Common to all examples is the attempt to develop distinct tactics for studying complex urban conditions and use a systemic approach to cope with the discovered pluralities and network of relations. The incorporation of this approach as well as data visualisation strategies provided the studio with valuable insights into the complex challenges faced by today's cities, informing ideas about rapidly changing cities and their resilient futures.

The two cities selected for research, Beirut and Samsun, were very productive examples, as both face an urban collapse at many scales. In the case of Beirut, problems related to the economy, urban management, transportation, lack of access to public and green spaces, and climatic risks are some of the issues that demand large-scale interventions and integrated urban strategies. The Beirut Port explosion on August 4th can be regarded as a natural consequence of this downfall at many stages. The blast created a ground-zero condition at the port area, reshaping the relation between land, the urbanscape, and the waterfront urban edge. Any attempt to understand the particularities of this case, the conditions before and after the blast, requires a deep and large-scale analysis of the many configurations of the city. The multicultural structure of the city, its historical significance, and its position within the region also play an essential role in understanding and reclaiming the city's urban qualities and role as an urban edge.

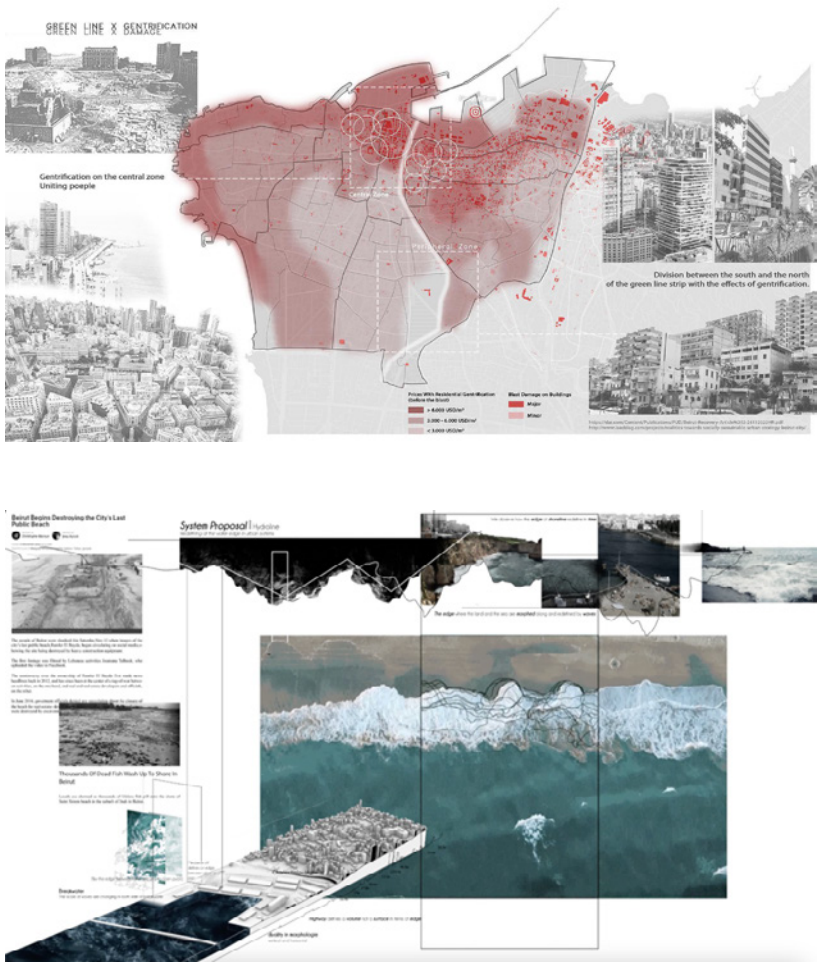

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Figure 1
Demarcations of Green Line and other forces that affect the emergence of new urban zones (Authors: Emine Koç, Melisa Yılmaz, Nisa Gülin Özkan, Zeynep Köksoy)

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Figure 2
Redefining the water edge (Authors: Cansu Sivrikaya, Sema Akbacakoğlu, Gizem Simay Engin, Almina Yakut)

RCL — Revista de Comunicação e Linguagens *Journal of Communication and Languages* N.60 (2024) ISSN 2183-7198

Perhaps Beirut's most important element is the **Green Line,** an urban entity that triggers different relationships regarding every period of the city, regionally, sociologically, and historically. However, it is not an inactive urban formation or a single line that demarcates two distinct parts within the city. Rather, it is an element of compromise and change, which is unique to the city of Beirut. Regarding its different roles and pluralities, the visualisation of data seeks to question and address the extent of associations and web of relations that can reveal the larger dynamics of the city. As seen in Image 1, the research collected and combined the data acquired from the Beirut Recovery Map (2024) to reveal the damaged buildings information after the blast and the changes in the prices before and after that event. The mapping of the information exposes the demarcations of the Green Line and other forces that affect the emergence of urban zones within the city, different from the accustomed typology of the city, which is divided into two parts, as displayed above (Image 1). The design idea generated the zones of differentiation and how Beirut experienced a change in its morphology following a catastrophic event. Furthermore, it is a way to interpret different layers of the city and the impact of these layers on each other, all of which can be considered as design data that initiates the design processes.

Redefining the water edge in urban systems is another type of inquiry, where dynamic data, like the constant change in the edge conditions of the coastline in Beirut, were analysed and visualised. The main idea of the research was to utilise variable and dynamic data such as climatic changes and tidal cycles as design input instead of more static geographic data. Non-human agencies (such as the changes in the shoreline caused by sea movements) were overlapped with more static geographic qualities or human interventions to initiate a holistic design approach for defining the coastal edge in a city (Image 2). This holistic approach integrated the data obtained from the constantly changing shoreline formation and provided an instrumental basis for the city's future scenarios. The notion of boundary and its architectural interpretations were analysed to explore interdependent variables. The research process also integrated the digitalisation of discreet data, which enabled the documentation of the changing water edge in relation to the general urban form.

In an effort of trying to map the relations between the coastline and the river in Beirut, another project recovered the data related to the **drilling of private wells** everywhere within the city. With these legal and illegal wells, the underground water fabric of the city of Beirut has been entirely changed by humans, and the water network of the city has assumed a completely different character. These private wells are criticised for introducing a marked rise in seawater infiltration, as the amount of extracted groundwater gradually exceeded the amount of natural recharge water. (Acra, Milki, Karahagopian, Raffoul 1997) Visualisation of this data provides a layout that unveils the unseen, unrecognised, yet quite vital aspects of urban culture. This endeavour should lead to the emergence of different design systems related to future water use in the city (Image 3). The data is visualised through the overlapping of different layers of information

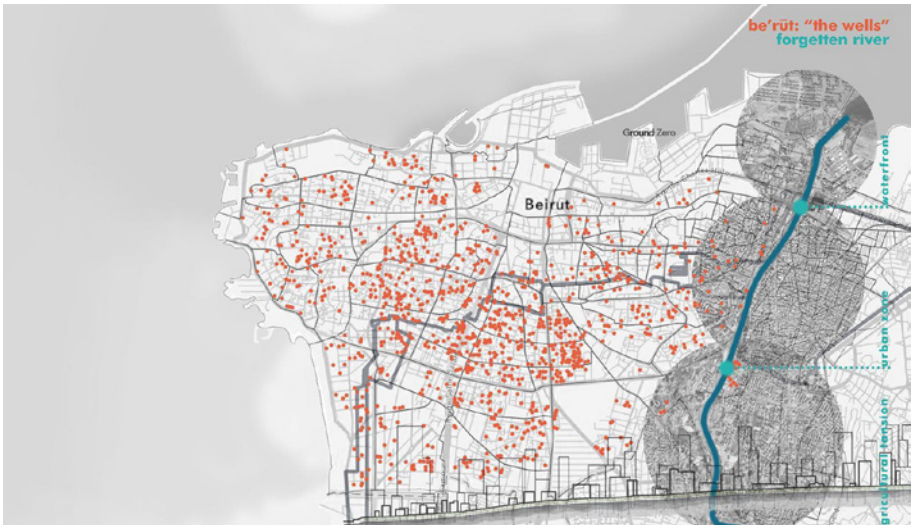

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Figure 3
Drilling of private wells throughout the city
(Authors: İlayda İlaslan, Mine Gülsün Kahveci, Seher begüm Boztepe, Semihanur Korkmaz)

— such as the wells, the riverbeds, the morphology of streets, and more — as discrete but interactive systems working with and affecting one another.

In another example, pollution was mapped as an environmental and climatic problem in Beirut. Pollution is one of the most pressing issues facing many of today's cities, and each city is expected to develop novel strategies to tackle this problem at multiple scales. Pollution threatens cities in many aspects, ranging from water pollution to air pollution to smaller-scale issues affecting streets, rivers, and other local environments. Beirut is also struggling with pollution at different scales and types. Research on pollution levels within the city should inevitably consider its causes and results, as well as the reciprocity between different types of pollution. In Image 4, the map integrates information on pollution acquired from municipal documents and other resources. Different layers of information directly related to or affecting the general level of pollution in the city — such as water pollution levels, the intensity of NO^2 due to traffic, pollution from waste, wind-distributed pollution, and the number of sea outfalls — produce a composite map, where different territories of pollution accumulation can be observed and worked on (Image 4).

Regardless of their subject of analysis, all the above-discussed examples address invisible or visible conditions and question how social, economic, and often political approaches transform the city. This is one of the most promising methods to understand

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Figure 4
Layers of Pollution in Beirut. (Authors: Doruk Özkoç, Ardacan Özvanlıgil, Emre Şimşek, Yıldız Cemaloğlu)

architecture's relation to the unknown and sometimes imperceptible. Thus, data visualisations, used in tandem with systems thinking, are considered indispensable tools for a (deep-)reading of today's cities.

The city of **Samsun**, an industrial harbour city on the northern coast of Turkey, copes with the consequences of various urban challenges, altering its social, geopolitical, environmental, and architectural conditions. Considered a logistical and industrial node in the northern region, Samsun has a transportation network connecting Anatolia to the Black Sea region through various means. Governing the national and international trade routes for years, the city has also been promoted as an agricultural hub, which augmented its geopolitical and geomorphological stance in the region. However, environmental degradation, urban destruction, and industrial policies have changed the urban conditions of the city, especially in the last decades.

One particular example involved extensive research, a broad-scale analysis that was not limited to the city of Samsun. The **Water Formation Library** can be regarded as a reading that (re-)defines the relationship of Samsun to water through the analysis of water textures of different cities, mapping the potential texture formations related to water movements. The project focuses on the *Mert Stream* in Samsun, which has lost its quality as a wetland due to uncontrolled uses. It aims to rehabilitate the stream and restore its irrigation potential as part of a larger-scale water network. To propose a system for this new network, the student group mapped the existing water patterns of several cities and constructed a comprehensive library, which was utilised during the design process. The collective mapping of the data provided different readings and associations which were not visible when analysed independently (Image 4).

On the other hand, **The Night Drift** project mapped the social conditions in a particular district of Samsun, which includes the port and the idle spaces in its hinterland. The map of human activity patterns at the port area at night and day revealed the city's voids, which are not only physical but also experiential, social, economic, etc. It is the visual documentation of what is not visually evident or easily accessible at first glance. The project tried to establish a framework for discovering the interrelationships between urban entities, making visible the complex network of the human flow alongside connected and disparate zones of interaction (Gehl 2001). It overlaps different activity patterns to reveal the legibility of the relationships between uncanny spaces, crowded spaces or spaces of attraction within the city that we do not perceive in our daily life, and most importantly addresses the relationship patterns that bring these differentiations and contradictions into existence. The design process builds on this unconventional data set, fostering a new understanding of the complexity of urban dynamics. Uncovering the patterns that lead to the emergence of certain urban conditions is regarded in the studio as a strategy for deep readings that configure a systemic and systematic approach to understanding the city (Image 5).

The selected examples emphasise the interrelations in the city and reveal complex relations, where various layers of data were overlapped and reinterpreted to arrive at a

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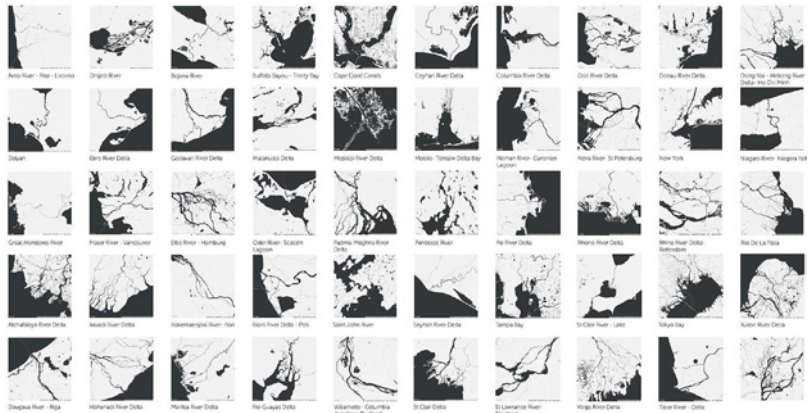

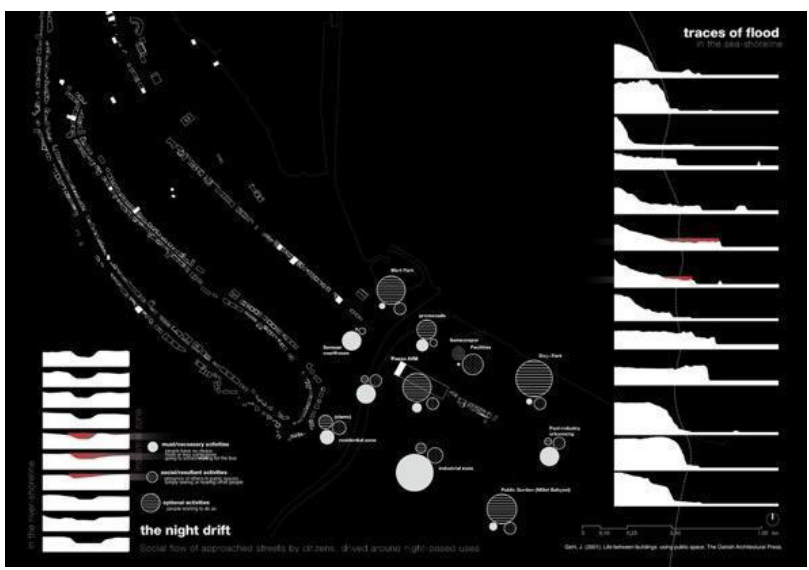

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Figure 5
A library of water-land relations. (Authors: Bartu Aydınlı, İlayda Ülgen, Zeynep Süner)

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Figure 6
Data visualisation displays the working hours of social spaces (café/restaurant, commercial facilities, social spaces etc.) and the related social flow of citizens in the city (Samsun). (Authors: Başak Ünver, Betül İlayda Yılmaz, Zehra Dağıstan)

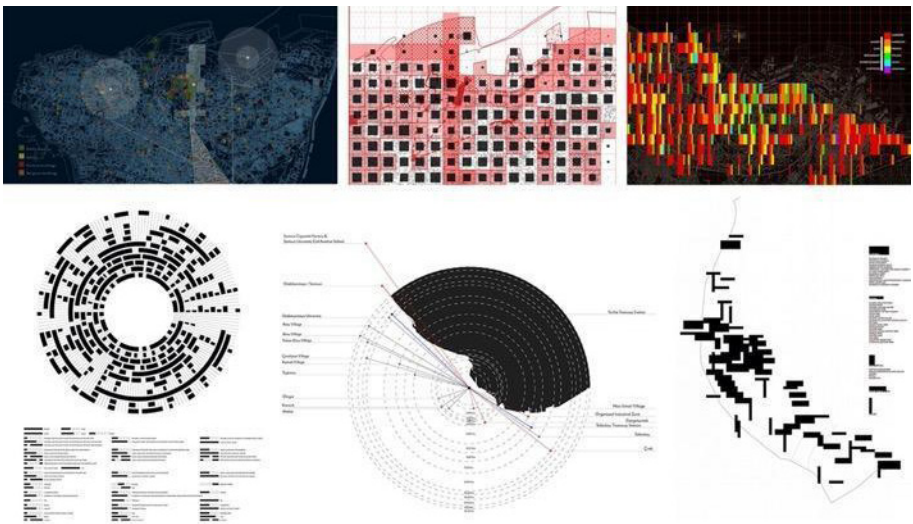

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Figure 7
Data visualisations of the urban data selected from two different studio processes.

series of urban representations. In the studio process, the data visualisations produced also created another data set that contributes to the learning environment of the studio. Each digital visualisation provides a different perspective on the urban conditions of the city and informs the reading of visible and invisible conditions. Although the article includes selected examples from studio productions, the visual palette of data sets defines an explorative ground for architectural research and design (Image 7).

4. A Survey on Methodology

An anonymous survey has been conducted with a group of students to deepen the outputs and reflections of the aforementioned studies. The aim was to understand the aftereffects of embracing systems thinking as a methodology in architectural design education and to reflect on the relationship between systems thinking, data visualisation, and urban conditions. The survey was applied to 25 students. The questions can be categorised into 5 main groups: 'experiencing systems thinking as a design methodology, its advantages and disadvantages in the design process, the integration of data visualisation into the design process, reading the information gathered at different scales (especially at urban scale) using this systemic approach, and the discrepancies between the approach and conventional architectural methodologies' (Image 8).

RCL — Revista de Comunicação e Linguagens *Journal of Communication and Languages* N.60 (2024) ISSN 2183-7198

The students indicated that the definition of the design process through the aforementioned methodologies enabled them to have a holistic view of the design problem. The ability to include multiple issues, organisations, and data sets was considered a challenging design task since it informed the questioning of the "unknown" or "invisible" conditions of the city. Besides the conventional materials used for analysing the city, such as maps, photographs, and drawings, among others, systems thinking was also mentioned to have a positive impact as it revealed the unique qualities of the city and opened up new grounds for design exploration.

Another important output received from the survey was that the students felt that dealing with the complexity of the city was a challenging task and had the opportunity to explore the potential of data visualisation techniques alongside systems thinking. They also noted the interactions between systems thinking and data visualisation processes and underlined how they supported each other, which is a positive output. Compared to conventional architectural design education experiences, the students also indicated the positive implications of dealing with the complexity and massiveness of digital data. The remarks from the students can be seen as a feedback loop that helps the integration of systems thinking in addressing large-scale architectural design problems.

The students also highlighted the difficulties of dealing with big data and the methods of visualising the data. Although data visualisation and data-driven representations are studied in other disciplines and are the object of extensive literature, their integration into architecture can be considered a novel approach. Therefore, the students need more theoretical and technical background to apply systems thinking. The students' level of proficiency with data visualisation techniques and ability to handle massive amounts of qualitative and quantitative data configure a shortcoming of the proposed exercise.

Digital competency and data literacy are two significant concerns that should be considered when using data-driven representation practices in architectural design and education because the designer's competency affects the complexity of the representation and, consequently, how it is read. In this sense, it should be noted that the technological transformation of architecture, design and its educational components requires the continuous update of related skills and mindsets.

Conclusion

The discussed research process was an attempt to test an experimental approach and to challenge conventional urban research methodologies, which remain insufficient to understand the complexity of today's cities. To propose a uniform method of urban analysis, or to suggest that data-driven representations or systems thinking should be used in design studios for all kinds of research and design, is not what was intended with these exercises. Instead, the aim is to provide an experience of the potential of data-driven practices that enable the gathering, processing, and visualisation of large

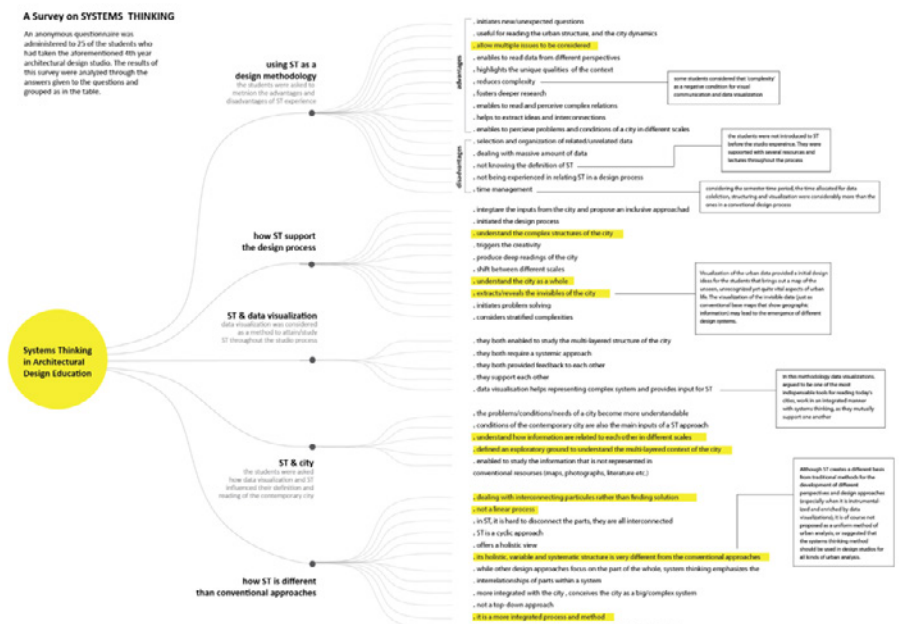

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Figure 8
The outputs of the survey on systems thinking in architectural design education.

RCL — Revista de Comunicação e Linguagens *Journal of Communication and Languages* N.60 (2024) ISSN 2183-7198

amounts of data, while also proposing a strategy for the integration of these practices into architectural design processes.

Since the examples that were analysed and discussed in this article are the result of an undergraduate study, they may not have the expected level of in-depth research background. Most of the research within the design studios benefited from the systems thinking approach and data-driven urban representation techniques. Although some research failed to respond to the complexity of systems thinking and data visualisations, they can still be considered a preliminary attempt regarding the adoption of this method in the context of the design studio. As argued in this article, systems thinking provides architectural research with new ways to engage with urban complexities, offering more open-ended, flexible processes of research and design compared to conventional methods. In the words of Senge, "systems thinking is a conceptual framework, a body of knowledge and tools that has been developed over the past fifty years, to make the full patterns clearer, and to help us see how to change them effectively." (Senge, 2006) Therefore, it can also be regarded as a suitable method for the elaboration of a response to the shifting conditions of the city and its components, including human and non-human aspects, a method that helps us understand the network of relations that structure the very essence of the contemporary city, with all its climatic, environmental, political and social problems.

The concepts of sustainable and resilient cities, along with the need to practice ecological approaches (in a wide sense), are acutely present in today's agendas and discourses on urban culture and beyond. In sum, ensuring the resilience of cities is a priority. In this sense, broadening architecture's research field is crucial for developing ecological approaches and creating a more sustainable future. Both systems thinking and data visualisation techniques can be regarded as means to unlock potentialities in the face of these challenges. Consequently, both are of paramount importance to architecture and architectural research and education.

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Acknowledgements

This ongoing research paper was initially presented at the Arts and Humanities in Digital Transition Conference in Lisbon, in July 2023. These exercise series are the result of experimental design processes developed in TEDU Faculty of Architecture, with the contributions of many partners. We would like to thank all the colleagues, who provided important input and feedback to the intellectual development of this assignment series and their execution in design studios in different years. In this respect, Alper Kiremitçi, Çağrım Koçer, Esatcan Coşkun, M. Ziya İmren, Onur Özkoç, Onur Yüncü, Utku Coşkuner provided valuable contribution as studio instructors.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

To cite this article

İnan, A. Derin, and Başak Uçar. 2024. "Data-Driven Urban Representations: Systems Thinking as an Operational Challenge for a Deep Reading of Contemporary Cities." *Revista de Comunicação e Linguagens* (60): 46-64. https://doi.org/10.34619/s36x-fy6z.

Received Recebido: 2024-01-31 **Accepted** Aceite: 2024-06-19