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Urban Design Evolved: The Impact of Computational Tools and Data-Driven Approaches on Urban Design Practices and Civic Participation

* Assist. Prof. Dr. **Ahmet Gün**
Faculty of Architecture, Istanbul Technical University, Türkiye
E-mail: ahmetgun@itu.edu.tr

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ABSTRACT

In recent years, the changing pattern of human activities, increasing data regarding the spatial environment, and the possibility of collecting and processing this data allowed us to reconsider how we approach urban design, with a focus on a digital-oriented and data-driven perspective. In this study, we examine the evolution of urban design by analyzing the roles of designers and citizen empowerment. Our analysis includes a literature review and semi-structured interviews with computational design experts. In this sense, the literature is reviewed to investigate previous discussions and findings about the topic, and semi-structured interviews were carried out with seven computational design experts. The experts were selected by considering two criteria: (1) their experience with computational urban design subjects in practice and (2) their academic research background. This study concludes that technology-driven urban design solutions change designers' relationship with data, opening new avenues for objective, data-driven & data-informed decision-making. There are few differences between traditional and computational design practices regarding user empowerment and participatory design. Moreover, technology-driven urban design tools and methods are still in their early stages and are rarely used in actual projects.

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Highlights:	**Contribution to the field statement:**
This study seeks to answer the following question: "How do technology-driven design tools and strategies alter the role and agency of actors and user empowerment in urban design?" - This study analyses the literature to gain a deep understanding of the conceptual and theoretical background and synthesize the basic concepts and critical insights about technology-driven urban design.	The use of computational design methods in urban design is a relatively new research topic. This article contributes to academia by exploring the impact of computational tools and data-driven approaches on urban design, shedding light on how technology-driven solutions change designers' relationship with data, promoting data-informed decision-making, and highlighting the evolving role of citizens rights in urban design processes.

***Corresponding Author:**
Faculty of Architecture, Istanbul Technical University, Türkiye
Email address: ahmetgun@itu.edu.tr

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1. Introduction

The studies of computational design methods in architecture can be traced back to the 1960s (Caetano & Leitao, 2020). Over time, these methods have advanced from the use of Computer-Aided Design (CAD) to code-based design allowing for a transition from top-down modeling to more generative, bottom-up systems. It causes interest in nature-inspired systems that have led to the creation of new design ecosystems around morphogenetic design systems and evolutionary software (Verebes, 2013). On the other hand, in an urban design context, the use of computational design methods is still in the experimental and research phase (Miao et al., 2020). Urban environments can be better managed, controlled, and designed with the increasing amount and variety of data generated by cities in the last decade (Kitchin, 2015). Moreover, with the increasing mobility of residents, studying cities has become more difficult and so researchers need to utilize different data sources to gain new insights (Balaban, 2021).

In contrast, traditional urban design methods that rely on static and sectoral approaches reach their limits in adapting to the increasing complexity and dynamics of cities (Miao et al., 2017). To overcome these limitations, designers need to find new ways to incorporate different data sources and cutting-edge design approaches into their work. This will enable them to make more objective and data-driven decisions in an effective way.

The use of computational design methods in urban design practices is a relatively novel research topic, and most of the studies show that their use is still in the early stages. However, there is a significant gap in the literature concerning the integration of participatory design approaches in these practices and the changing roles and agencies of designers in the computational design process. Therefore, this study aims to review the evolving urban design process in the digital age in terms of the role of designers and the affordances of these tools and strategies for user empowerment. To do this, we critically examine the paradigm shift in urban design practices in the digital age and provide some suggestions for successful urban design practices. With these goals in mind, this study's primary research question is:

- How do technology-driven design tools and strategies alter the role and agency of actors and user empowerment in urban design?

With this primary question in mind, we identify several secondary research questions as follows:

- What effects have computational urban design tools and technologies had on the traditional roles and agencies of designers?
- In what ways have these tools affected the decision-making process in urban design practices?
- How technology-driven urban design solutions can change citizen empowerment and participation in city-making practices?
- Lastly, what are the limitations of technology-driven urban design methods in urban development practices?

In methodology, we analyzed the literature to gain a deep understanding of the conceptual and theoretical background and synthesize the basic concepts and critical insights about technology-driven urban design. Moreover, we interviewed seven computational design experts using a semi-structured format to gain further knowledge[1].

In the next part of our research, we provide a state-of-the-art critical overview of traditional design and technology-driven design processes. We also briefly present the theoretical and conceptual background of "Technology-Driven Urban Design." The third section of our study will focus on the technology-driven design process and will examine the roles of the designer and citizen empowerment. In the fourth section, we will discuss our research findings and explore key factors and directions for future research.

[1] In this study, all information about interviewee are coded in order to protect their personal data.

2. Technology-Driven Urban Design

Urban design is a vast field of activity, encompassing numerous processes from building site's physical design to participatory planning processes. Urban design is the tool for reshaping urban space to accommodate new urban conditions (Madanipour, 2006, p. 191). In this study, we use the term "urban design" as a study and practice area located at the intersection of architecture, urban planning, and urban studies (Gün et al., 2020). Cozzolino et al. (2020) analyzed the 12 urban design scholars to define urban design and its primary dynamics. After in-depth analysis, they define "urban design" as: "a creative and purposeful activity with collective and public concerns that deal with the production and adaptation of the built environment at scales more significant than a single plot or building." As Steino et al. (2013) argue, urban design practices should be situated as an interdisciplinary and inter-scalar design activity. Urban design has been accepted as one of the collaborative design atmospheres where architects, planners, landscape designers, and other disciplines work together.

Urban design processes involve different design and action phases. In literature, there is a different kind of urban design phase classification. For instance, Carmona (2014, p.6-11) identifies the urban design process as a "four active place-shaping process": (1) design; (2) development—shaping the physical public realm for use; (3) space in use; and (4) management—shaping the social public realm through use. Boyko et al. (2005, p. 120) also identify four different urban design phases: forming goals (1); design (2); evaluating/selecting/creating a plan; and finally implementing/monitoring and following up on design solution (4). However, these steps can be useful for the traditional urban design process. Thus, a new classification is required to include both traditional and technology-driven urban design processes. In this study, we focus on the early stages of the urban design process (ideation and conceptual design phases), where the collected data is analyzed, the main design criteria and evaluation parameters are addressed, and the main design goals are identified accordingly.

2.1 Traditional Urban Design vs. Technology-Driven Urban Design

With the development of urban analytics and computational design tools, the types and amount of urban data are increasing, and new possibilities to design cities emerge. The technological developments in GIS, Big Data, Urban Analytics, the Internet of Things, and the possibilities of collecting different kinds of data like authoritative, crowdsourced, and remotely sensed data open new avenues for data-driven urban design practices (Gil, 2020). It is possible to track individually produced data via sensors and mobile phones, social media posts, online activities of humans, and volunteered crowdsourced data. Furthermore, the behavior and movements of residents are different compared to the past, and cities need to be shaped with more complex objectives coming from industry, public, and environmental requirements. Kitchen (2015) argued that this new era changes the structure of "data-informed urbanism" that is replaced by "data-driven, networked urbanism."

All of these changes require to rethink of urban design from the "digital age perspective." This study defined "traditional urban design" as a design process based on drafting-based (CAD) techniques that are more heuristic, designer-oriented, and non-discursive. On the other hand, "technology-driven urban design" can be defined as a design process that combines designers' creativity with digital computational techniques through rule-based systems involving measurable constraints, parameters, and relations.

In this period, traditional urban design techniques have been criticized for being based on static and sectoral approaches (Miao et al., 2017), non-dynamic, and time-consuming (Steino et al., 2013). This approach also regards city-making as a non-flexible and static design process (Verebes, 2013). In this sense, it is argued that traditional urban design techniques reach their limits to keep up with cities' complex dynamics and growing demands from multiple stakeholders.

In the computational design process, the designer does not directly model the design object; instead, he develops a graph or script whose operation/execution generates the model, and if a minor edit is executed to the graph or script, it could have a significant effect on the generated object that enables to the exploration of a wide range of design alternatives (Aish, 2013). For instance, the designer does not expect to draw the line directly in the parametric design process. Instead, the designer specifies the editable attributes of the line (the length, initial point, and direction of the line), and the model generates its associative geometry (Çalışkan, 2017). In this process, urban designers are expected to be involved in two primary design operations:

(1) Devising the core setting of the generative algorithms by design rules,
(2) Evaluating the emergent design forms in terms of the constraints set by the context and the preliminary design criteria (Çalışkan, 2017, p. 436).

Thanks to computation, it is possible to produce contextual and actionable data that can be shared across systems, enabling a more holistic and integrated view of urban areas. In the era of the digital age, the computational design process offers many benefits in the city-making process, such as managing complexity, optimizing specific criteria, incorporating a wide variety of data and information layers from past projects, and offering a "live model" for post-occupancy adaptation (Walmsley & Villagi, 2019). It also enables parallelizing design tasks, managing large amounts of information, incorporating changes quickly and flexibly, and assisting designers via automated feedback, such as mapping simulation results (Caetano et al., 2020, p. 290). Several tools have been used in computational design practices as follows:

- Generative modeling interfaces such as Grasshopper 3D and Dynamo,
- Parametric urban design software such as CityCad and CityEngine,
- Optimization plugins to guide the generation of solutions such as *Galapagos*, *Silvereye*, *Radical*, *Opossum*, and *Goat* (for single-criteria optimization) and *Wallacei* (for multicriteria optimization) (Lima et al., 2021)
- Several analysis and simulation tools/plugins, such as *EnergyPlus* (for simulating energy consumption), *Ecotec* (for analyzing daylight), Ladybug (for analyzing weather data), *Radiance* (for lighting simulation), and *Butterfly* (for fluid dynamic simulations).

As explained above, the technology-driven design approach alters design practices in terms of many aspects. To sum up, while traditional urban design relies on heuristics and capabilities of designers and computer-aided design (CAD) techniques, technology-driven urban design integrates digital computational design methods with objective & and measurable constraints and parameters. Table 1 summarizes the differences between traditional and technology-driven urban design approaches.

Table 1: The comparison between traditional urban design and technology-driven urban design approaches (Prepared based on Verebes, 2013; Kitchin, 2015; Deutsch, 2015; Çalışkan, 2017; Caetano et al., 2020; Gil, 2020).

	Traditional Urban Design Approach	**Technology-driven Urban Design Approach**
The relationship with computer	Computer-Aided	Computer-Oriented
Design object created with	Shapes, geometric relations	Parameters, constraints, algorithms, rules, mathematical relations, data structures
Design Process	More heuristic, non-discursive, draft-based	Discursive, script-based
The relation with data	Data-informed & Data-enabled	Data-oriented & Data-centric
The Generation of Design Object	Anticipated	The generation of unanticipated design objects is possible.

In this study, we focus on using one of the computation-based design approaches: generative design. Compared with architectural design, using generative design solutions at an urban scale is a relatively new approach (Miao et al., 2020). Its potential has yet to be comprehensively explored. This process is based on several technologies involving: (1) parametric design software to model the space of possible solutions, (2) simulation software to derive metrics for evaluating each potential design, and (3) optimization solvers, e.g., Genetic Algorithms, that can automatically search through the design space to find the most optimal designs (Nagy et al., 2018). Until now, a limited number of studies have explored the application of the generative design approach at the urban design scale.

In recent years, there has been an increase in digital tools for urban design that apply computational design methods and data analytics strategies, such as *SpaceMaker*, *Giraffe*, *Digital Blue Foam*, and *Scout* (Calixto et al., 2021). The phases of generative design processes have been tried to be classified in several studies. Wilson et al. (2019) developed a methodology for applying computational urban design in four steps: 1) Define Inputs & Design Space, 2) Procedural Geometry Generation, 3) Performance Evaluation, and 4) Analysis, Communication & Stakeholder Engagement. In literature, a few design experiments have been conducted to show the potential of the generative urban design process. One of the practice-based generative urban design studies was done in 2017 by the Dutch development and construction company Van Wijnen. Nagy et al. (2018) presented this generative design experiment in four steps as follows:

Step I. Creating a design space model that can generate various design solutions subject to the problem's constraints (Figure 1).

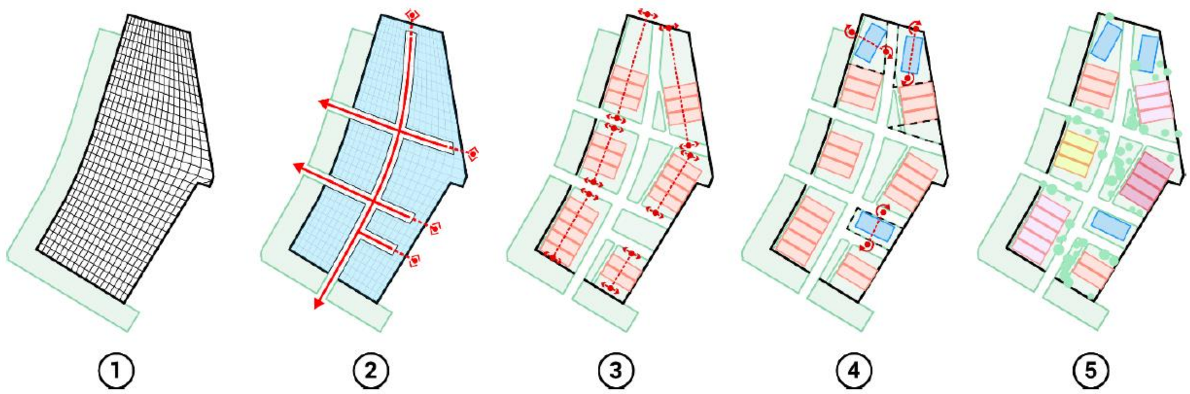

Figure 1: Five steps of describing a parametric design model for generating each design option: (1) create a mesh from the boundary; (2) generate streets; (3) subdivide into lots; (4) place housing units; (5) place apartment buildings (Walmsley & Villaggi, 2019).

Step II. Defining design goals to evaluate the performance of each design. In this phase, the design space model needs to include one or more metrics that can be used as objective targets during optimization: the profitability of the project for the developer (financial goal) and the potential solar energy that can be captured by the roofs of the residential buildings (environmental goal) (Figure 2).

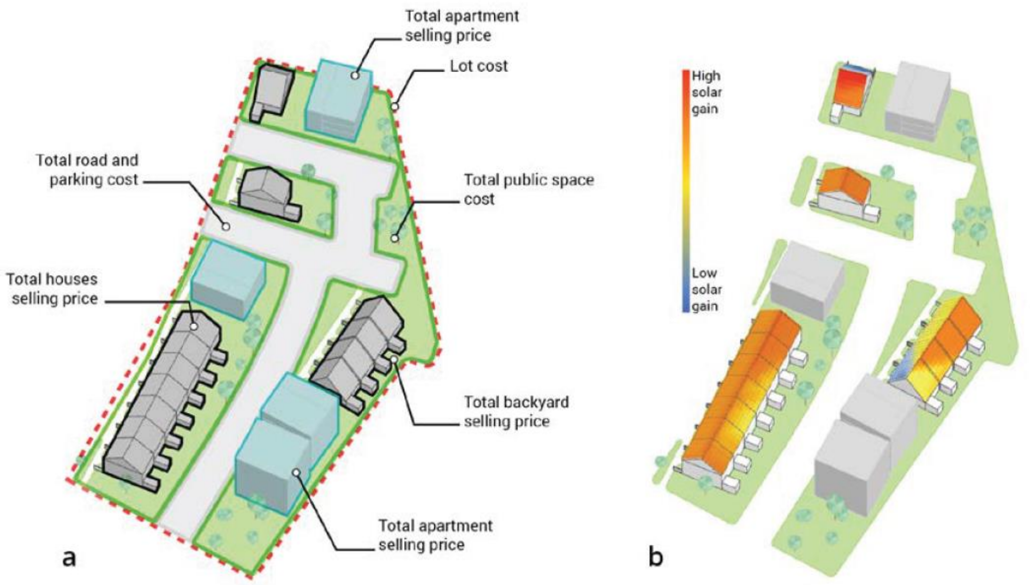

Figure 2: The definition of goals through metrics, development profitability (a), and potential for solar gain (b) (Nagy et al., 2018).

Step III. Design space analysis through the use of metrics.

Step IV. Design optimization to find the best alternative that maximizes the values of the determined objectives. In this phase, the optimization trial consisted of 200 generations with 200 designs in each generation using the Genetic Algorithm (Figure 3).

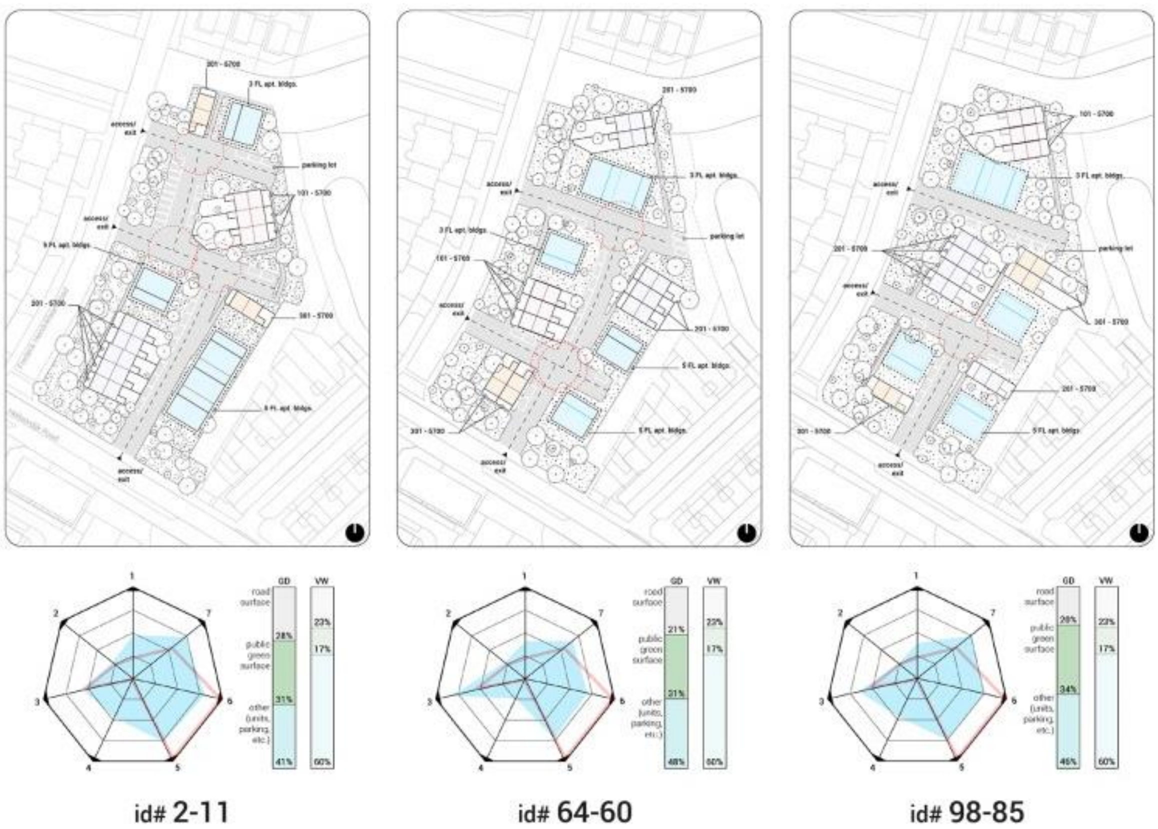

Figure 3: Selected and refined high-performance design based on identified metrics (Gerfen, 2018).

2.2 Previous Studies in Literature and Filled Gaps by This Study

To review the literature, we did a state-of-the-art critical overview of using the computational design approach in urban design processes. In this context, we reviewed the research to find out what is already known about our study area by doing a systematic search of several databases (Scopus and Web of Science) and some proceedings books relating to computational design, e.g., eCAADe (Education and research in Computer-Aided Architectural Design in Europe) and CAADRIA (Computer-Aided Architectural Design Research in Asia). A wide range of researchers have studied computational urban design with a variety of purposes: (1) testing novel generative and analytical methods in urban design practices (Bielik et al., 2022); (2) integrating participatory approach in computational urban design (Daher et al., 2018; Knecht et al., 2019); (3) examining the effect of ICT in professional urban design practices in terms of decision-making (Al-Douri, 2022); (4) critically reviewing the use of parametric design in urbanism (Çalışkan, 2017).

One of the prominent works regarding applying generative design solutions in urban design is done by Koenig et al. (2020). They developed a data structure accommodating flexible urban design problems to overcome the challenges of integrating urban analytics and generative methods. This study also generated urban design variants by combining urban analysis and evolutionary multi-criteria optimization (EMO) methods.

Several authors have explored the use of optimization methods in urban design processes. Miao et al. (2020) presented design optimization methods by reviewing them from historical development and future trends, and they showed the advantages and challenges of design optimization methods. Lima et al. (2021) conducted a series of case studies to evaluate and present the benefit of using optimization tools to improve urban performance. This study compares the effectiveness of various optimization algorithms in solving urban design problems and assesses generative approaches. Nagy et al. (2018) showed the potential of the generative design approach for solving complex urban design problems through a series of workshops for designing a residential area in the Netherlands. Knecht et al. (2019) developed a computational approach that allows designers to share a subset of the design space with citizens via an online interface named *Beta.Speckle*. This study evaluated the tool's usability in participatory urban design processes.

As seen in the literature, although the use of several generative design methods, e.g., design optimization, dates back to the 1960s in architectural design, most of the research and experiments have been carried out in the last years in urban design processes, so we can conclude that the use of these methods in an urban design context is still in infancy phase. In literature, many studies have carried out pilot studies to test and evaluate the affordances, limitations, and potentials of the computational urban design process. As mentioned, a few studies focus on integrating a participatory design approach in the computational urban design process. In addition, the studies in the literature have yet to evaluate the role of urban designers and their agencies in computational urban design processes. In this study, we aim to fill the gaps in the literature by tracing the changing pattern of the urban design process in terms of (1) the role of designers and (2) citizen empowerment.

2.3 Methods of Data Collection

This research has been pursued in two phases: a literature review and interviews followed by a discussion of the findings. This study aims to review the changing pattern of the urban design process in the digital age in terms of the role of designers and the affordances of these tools and strategies concerning user empowerment. We also aim to critically examine the paradigm shift in urban design practices in the digital age. To do this, we need to review research findings in the existing literature and address research gaps concerning selected research topics. To do this, we firstly conducted a literature review as the first phase of our research methodology. The literature review has focused on reviewing secondary sources to construct theoretical propositions. The second phase involves a semi-structured interview with seven computational design experts. In this sense, we identified two criteria for the selection of experts for the interviews: (1) having experience in using computational design tools in design practices and (2) having academic expertise in computational urban design.

Based on the introduced research questions in the first section, in semi-structured interviews, the experts were asked some questions under thematic topics as follows:
(1) how do computational design tools, methods, and strategies change the urban design process? What are these novel methods' key similarities and differences with the traditional urban design process?
(2) the potential of cutting-edge computational tools in urban design practices;
(3) how the computational design approach changes the role of urban designers;
(4) their effect on citizen empowerment and design collaboration.
As the literature is not rich in the focus research area, we use expert interview notes as a complementary source.

3. Toward a Technology-Driven Urban Design: Critical Reflection

Based on the theoretical literature review, similar research findings, and expert interview notes, we critically discuss how the technology-driven urban design approach has altered the designers' role and actions in the design process and their relations with data. Finally, we examine whether this approach changes the urban design process regarding user empowerment and participation.

3.1 The Designer's Role and Responsibilities in the Design Process

Designers are expected to gain new capabilities and be responsible for carrying out new actions to keep up with the recent developments in the "digital age". Leach (2009, p.35) argues that the designer's role evolved from creative "form-giver" to the controller of generative processes in the digital age. Due to the complex nature of computational urban design processes and their multitude of interests, this process inherently requires complex workflows and a collaborative design approach (Steino et al., 2013). In this sense, the following questions come to the fore:

- How do technology-driven urban design tools and methods change urban designers' roles and responsibilities in the design process?

Although the discussions regarding technology-driven urban design have yet to mature, we discuss this issue in light of several arguments proposed to answer this question. Liao (2015) argued that as the clients demand more value from the projects and cutting-edge technologies, the designers are expected to gain skills like data mining, automation, coding, etc. In this context, Deutsch (2017) introduced a new kind of designer entitled "super-users" who is expected to take a role that is the convergence of designer, data scientist, and algorithm builder (Figure 4).

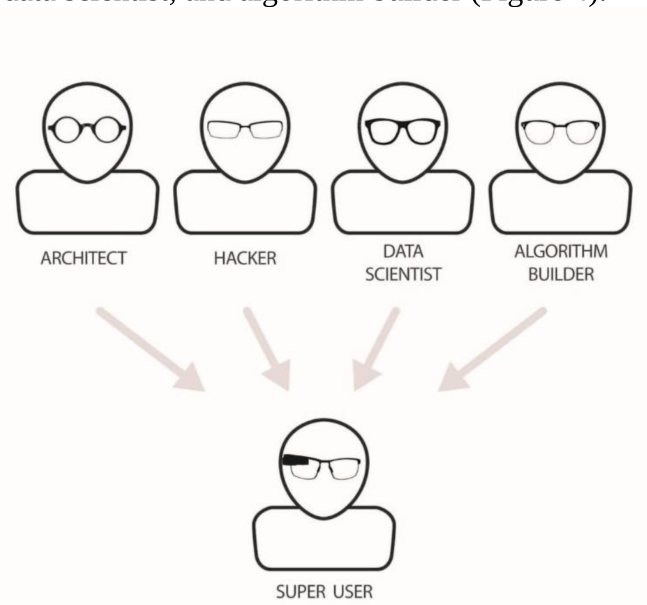

Figure 4: New roles that are expected to be taken by designers (Deutsch, 2017).

However, for now, when it comes to the urban design context, which is inherently based on a collaborative design process, urban designers rarely take on this new responsibility for several reasons.

Firstly, suppose urban designers try to take on a new role like an urban data scientist or a computer programmer by processing different data layers or writing a script. In that case, they may not sustain their inherent and heuristic design capabilities, and they need to reconstruct their way of design thinking (Expert 3, personal interview). Instead, urban designers are expected to rationalize design through explicit computational design elements, e.g., parameters, constraints, and design rules, to be integrated into the algorithm by programmers, so urban designers are expected to have basic operational knowledge of computation (Çalışkan, 2017).

Urban designers also need to collaborate and communicate with actors such as computer engineers and urban analytics experts to write scripts and collect and process data (Figure 5). Moreover, urban designers are required to learn to design processes through algorithms. For this purpose, they are expected to develop their algorithmic thinking skills and externalize the design process by leaving abstract definitions. In addition, as technology-driven urban design processes inherently depend on structuring "well-defined problems", urban designers need to divide design problems into sub-thematic problems (Expert 1, personal communication).

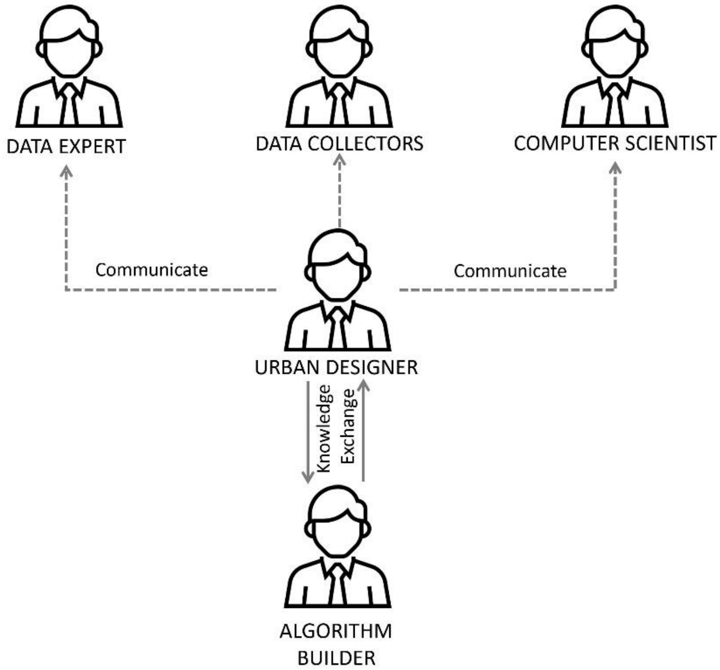

Figure 5: The expected actions from urban designers in the digital age.

The urban design process requires using a wide variety of data sources. Traditional and technology-driven urban design processes are expected to gather thematic data layers in different areas such as walkability, liveability, physical environmental conditions (wind, thermal, etc.), urban morphology, circulation, and accessibility. In the digital age, it is also possible to make use of novel types of data in the design process, such as monitoring citizens' unanticipated behaviour patterns in urban spaces, tracing the quantitative data from apps and sensors (Balaban, 2021), and collecting users' expectations from the project (Jutraž & Le Moine, 2016; Falco & Kleinhans, 2018). The involvement of these kinds of data requires using cutting-edge data analysing techniques. Thus, urban designers must communicate with data scientists and find the best ways to integrate this data into urban design.

In addition, one of the main challenges of computational urban design processes is a suitable representation of urban design problems. To overcome this challenge, categoric data classification is needed to address problems (Koenig et al., 2020). The design of urban areas requires the involvement of many design goals that influence urban development, and these goals are inherently conflicting and necessitate preference-based decisions (Showkatbakhsh & Makki, 2022). As seen in the example shown in the previous section, it is possible to face conflicting design parameters such as profitability, sustainability, and interest of different stakeholders. It is a challenging task and responsibility to identify, filter, and select design objectives for the urban designer. Especially in the "definition of goals" phase and to identify each thematic subject's objectives, constraints, and metrics, urban designers need to communicate and collaborate with different expert groups to make decisions. In this process, they are expected to use these data and information sets to create a design solution space. After that, they determine the "satisficing" solutions based on the predefined metrics and their experience.

In this process, the most challenging situation faced by urban designers is sustaining their experience and intuitive and heuristic way of design thinking and adapting themselves to the language of "computational design thinking" simultaneously. It is difficult to carry out a meaningful urban design process "just" based on successful data processing operations and well-integrated computational design tools (Expert 4, personal communication). As seen in the example shown in the previous section and generative design processes, urban designers actively create a design space model, define and control design goals, and analyze the design space by using their intuitive power. Furthermore, the urban design process is inherently based on solving many "wicked" problems that cannot be addressed discursively, so computational design approaches can not be used easily in these cases.

One of the wrong assumptions about technology-driven urban design is that computational design tools will take over the role of the designers. The question then arises as to whether the computational design process, in which large portions of the design process could become automated, meets all criteria plus common sense (Deutsch, 2017). The experiences gained from the practices show us that urban designers will always be responsible in the design process by designing systems, defining rules, and building algorithms. By doing these actions, designers formalize the design process and use built algorithms for their design objectives (Dino, 2015). Unless urban designers build algorithms sufficiently and involve required data layers in the design process, the computational tools will not generate high-quality design output (Expert 7, personal communication). Even though designers may take advantage of the full power of computation, their responsibilities will exist forever.

3.2 User Empowerment & Participation

Different from architectural design practices, many people are affected by urban design decisions, and a wide variety of public issues are expected to be involved in urban design. However, traditional participation methods, e.g., referenda, public hearings/inquiries, citizens' jury/panel, consensus conferences, public opinion surveys, and focus group meetings (Rowe & Frewer, 2000), are sometimes criticized since their ability to the engagement with the public and the encouragement of exchange of ideas were limited that reduce the effectiveness of tools and difficulty in evaluating decisions (Fares et al., 2018, p. 1822). These methods generally depend on a particular place and time, and they are generally insufficient in terms of time, economy, and user satisfaction (Innes & Booher, 2004).

Technology-driven urban design tools and methods bring new opportunities for user empowerment and participatory design by removing the barriers of space, time, and technical issues in carrying out participatory design actions and facilitating the analysis and evaluation of collected data. Today, a range of digital media affect our lives and are increasingly embedded in the urban fabric, which monitor or reproduce urban rhythms and be instrumental in reshaping and regulating the interactions and practices of everyday urban life (Papangelis et al., 2023). These technologies also affect public participation and design empowerment in urban design practices. Therefore, new concepts have emerged with the effects of these developments within the intersection of participatory design and Information and Communication Technologies (ICT). We use the term "technology-driven participatory design" to define the use of ICT-enabled tools for the involvement of citizens in design processes. Technology-driven participatory design activities range from the passive participation of users through the involvement of their data, called "participatory sensing," to the collection of their desires from the projects and involving them in the inquiry of design alternatives.

Participatory sensing can be defined as the integration of users in the collection and acquisition of datasets about urban areas through the use of mobile devices and personal data sources to enable public and professional users to gather, analyze, and share local knowledge (Burke et al., 2006; Höffken &

Streich, 2013). Through this approach, it is possible to collect people-centric sensing, such as documenting activities and understanding the individuals' activities and behaviors by registering their location information, such as GPS location and activity information (Keseru et al., 2019). While the users have a more passive role in the participatory sensing approach, they can actively involve the design process in other technology-driven participatory actions.

With the use of mobile participation apps, e.g., FixMyStreet and FlashPoll, and web-based platforms, e.g., Maptionnaire and Qua-kit, citizens can enable to submit their desires and expectations from the project (Hasler et al., 2017; Falco & Kleinhans, 2018). In addition, users can experience design alternatives and contribute their design ideas to the process via immersive environments such as Virtual Reality, Augmented Reality, and Mixed Reality apps. Some studies show us that using these environments enables us to benefit from spatial and contextual cues and motivate more citizens in urban design processes (Saßmannshausen et al., 2021). They are useful in negotiating design decisions, discussing the quality of design alternatives (van Leeuwen et al., 2018), and increasing users' willingness to participate in the process (Boos et al., 2022). Additionally, the use of digital games is effective in supporting civic learning (Devisch et al., 2016), useful in the co-creation of urban areas and public places, motivates a broad audience (youth in particular) to participate in the design process, and enables participants to develop and present their own opinions on the 3D environment (de Andrade et al., 2020; Delaney, 2022). Table 2 shows a distribution of technology-driven participatory tools by actions involving data types and examples.

Table 2: Participatory design actions and the type of data involved, possible tools and technologies used in technology-driven urban design processes.

Participation Action	The Type(s) of Data Involved	Possible tools and technologies	Example
Participatory Sensing (Kanhere, 2011; Balaban, 2021)	Users' Locations & Actions Measure Urban Behaviour Sensor data collected from public areas	Static Sensors (e.g., Automated Counting and Other Sensors) Mobile Sensors (GPS, Accelerometer, Mobile Phone, Specialized Sensor Device) Big Data (e.g., Mobile Phone Positioning (MPP) Location Based Services (LBS), Social Media)	BeWell Project BlueStates CenceMe WideNoise
Collecting Desires and Expectations from the Project (Ertiö, 2013; Hasler et al., 2017; Falco & Kleinhans, 2018)	Users' placemarks and descriptive data Tagged content based on predefined categories Text-based comments	Mobile Participation Apps Web-based Participation Platforms	FixMyStreet FlashPoll Maptionnaire Qua-kit
Collecting/Developing Design Proposals (Devisch et al., 2016; Delaney, 2022; Alonso et al.)	Drawing users' polygons on maps Describe ideas on 3D models	Digital Games Mixed Reality Platforms	Participatory Chinatown CommunityPlanIt BlockByBlock CityScopeAR
Public Inquiry about Design Alternatives (de Andrade et al., 2020; Boos et al., 2022).	Text-based feedback & tagged content on experienced design Reactions and reflections of users on design alternatives	Digital Games Virtual Worlds Mobile augmented reality apps	NextHamburg Second Life platforms (Terf) UrbanCoBuilder

However, technology-driven urban design approaches have several shortcomings regarding user empowerment. First, the technology-driven participatory tools and methods are often ill-connected to computational design processes due to the lack of common platforms and difficulties in integrating this input (Knecht et al., 2019). Similarly, as computational design practices are based generally on

contextual and physical related constraints, the participation of users, which depend on the inclusion of non-physical factors about human preferences, cannot be realized sufficiently (Daher et al., 2018).
In addition, expert interview notes reveal the other drawbacks concerning integrating participation input in computational design processes. For instance, optimization methods depend on searching for the "perfect fit solutions" based on predefined metrics. This kind of approach prioritizes effectiveness and efficiency. However, the performative logic of technology-driven design may cause a conflict with the desires and habits of citizens. In this context, several questions come into prominence regarding urban life (Expert 2, personal interview). For instance, how effective is the creation of a cul-de-sac in the city-making process, which is an essential element for privacy and security in Islamic cities, regarding the metrics of accessibilities? Similarly, how efficient is planning organic city patterns and designing blank walls regarding perceptibility, walkability, and visibility metrics? Moreover, what if the users' expectations and desires from the project contradict the rational logic of technology-driven urban design?
Technology-driven urban design approaches still have some limitations in using "non-discursive" data, e.g., socio-cultural data of citizens and non-visible/grounded values of the area, which can not be easily parameterized (Expert 1, personal interview). Unless these data are integrated into the design process, a technology-driven approach may reduce urban design to the basic optimization process where only structured discursive problems can be solved through identified metrics. This may cause the creation of generic cities where the unique characteristics of the cities are lost, and citizens' space usage habits, needs, and desires are excluded. As a result, the cities will possibly be developed and transformed based on the goals defined by the collaboration of corporations and urban designers entitled "corporate urbanism" (Expert 7, personal communication).

4. Discussion

Thanks to the increasing capabilities of computational tools, urban analytics techniques, and possibilities to collect and process a wide range of urban data, technology-driven urban design approaches have provided many opportunities to urban design professionals. Technology-driven urban design tools enable examining the performance of existing areas or simulating produced urban design solutions based on defined objectives and parameters. While the traditional urban design approach is mainly based on more heuristic, non-discursive and draft-based design process, technology-driven urban design lies on the script-based and discursive design process. While the former is a data-informed and data-enabled approach, and the latter adopts a data-oriented and data-centric approach. In this sense, it incorporates digital computational design methods with objective and measurable constraints and parameters.
In the digital age, it is possible to involve many people in participatory design actions without space and time-related barriers. Nevertheless, many new issues regarding urban designers' role and user empowerment in technology-driven urban design processes need to be discussed. In this section, based on our research questions introduced in Section 1, we critically discuss how technology-driven design tools and technologies alter urban design practices and give some suggestions.

The Roles and Agencies of Designers in the Decision-Making Process: Urban design is a collaborative practice where architects, planners, landscape designers, and social scientists exchange opinions and deliberate on project issues. In the digital age, the urban design process incorporates different data sources such as physical and socio-spatial analysis of the area, environmental, authoritative, crowdsourced, remotely sensed, and social media data. Urban designers need to communicate and collaborate with urban data scientists and algorithm builders to extract meaningful information from the collected data. In addition, urban designers need to collaborate with experts from different areas so that they can properly define problems, identify goals through metrics, and create design solution space.
Furthermore, it is possible to encounter problems in identifying design goals when some conflicts happen in defining different parameters, such as environmental, economic, and social issues. Hence,

there is a need to provide a collaborative workspace; we use the term “expert collaboration platform” in this study that not only (1) provides a data panel allowing different expert groups to upload data and access the data pool, including different thematic data layers that collected by different actors in the design process and take decisions based on the deliberations but also (2) ensures urban designers to collaborate with data experts to extract meaningful information and knowledge from collected data in one shared interface like data dashboards. This platform can open new avenues to juxtapose and superimpose different data layers for data visualization and analysis. It can also be used for project management by enabling responsible actors to monitor data flows and manage workflows (Gün et al., 2021).

Defining design solution space based on identified problems and metrics is essential to carry out successful technology-driven urban design practices. Urban designers must try to address urban design problems discursively and identify thematic parameters accordingly. However, urban design inherently involves many “non-discursive” issues that cannot be entirely codified by explicable parameters (Çalışkan, 2017). For instance, citizens' sociocultural data, the area's local context, and citizens’ needs and desires from the project cannot be easily defined as goals through metrics.

“*Only “well-identified problems” can be solved perfectly through computational design methods. What about the other types of problems? In this context, the leading role of the urban designer in creating a solution space for overcoming “non-discursive” problems is important*” (Expert 3, personal communication).

Moreover, urban designers should avoid structuring urban design processes based on “only” quantitative data because this approach may reduce the urban design process to an “engineering optimization process” (Expert 4, personal communication).

“*It is essential to benefit both from the discursive & rational power of computation and the non-discursive, heuristic & intuitive way of design thinking*.” (Expert 2, personal communication).

In this sense, it is necessary to balance them, so urban designers are expected to move between traditional and computational design approaches like a pendulum (Figure 6).

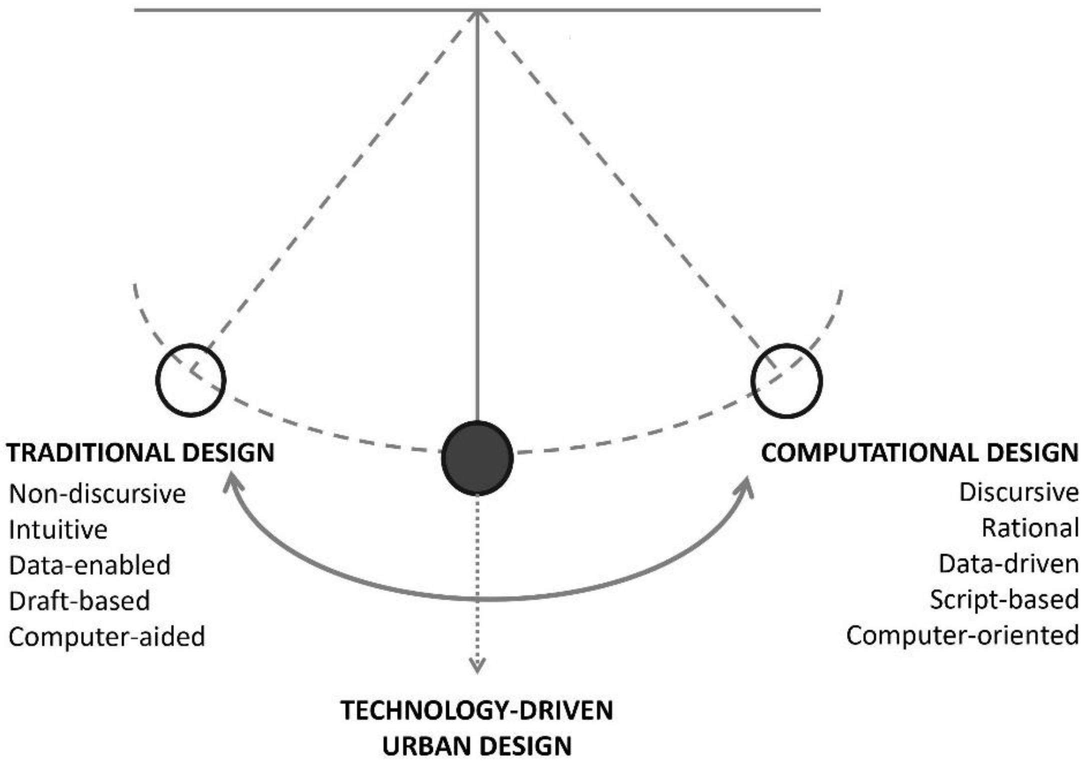

Figure 6. The situation of technology-driven urban design: The pendulum moving between traditional and computational design.

User Empowerment and Participation: As mentioned in the previous section, even though it is possible to involve citizen input through different kinds of technology-driven participatory design actions, e.g., participatory sensing and public inquiry about design alternatives, urban designers have faced some problems in integrating participation input in computational design processes (Knecht et al., 2019). Moreover, the nature of non-physical factors related to participation data can not be easily parameterized (Daher et al., 2018). This may cause the exclusion of these data types in urban design practices. In addition, as an interviewed expert noted:

"*It is possible to encounter conflicts between the performative logic of the computational design process and human desires and their daily living habits*" (Expert 2, personal interview).

Thus, urban designers need to find new ways to integrate non-structured data in the process and control the consistency of computational design inputs with user expectations and socio-cultural values of the areas in the early design phase.

Based on these findings, developing an integrated collaborative and participatory framework that can be used in technology-driven urban design practices is necessary. First, before creating a design space model, both thematic physical data layers, such as walkability, physical environmental conditions, accessibility, and non-discursive data sets, e.g., users' actions and space usage habits, should be collected and analyzed based on the consultation between experts. In defining design goals, the participation of users is very critical. In this phase, users' expectations and desires from the project can be collected through technology-driven tools, e.g., web-based platforms, mobile participation apps, and traditional participation techniques. This data should be used as one of the dimensions in defining design goals. Additionally, design alternatives can be shared with participants in the design optimization phase. Citizens can experience design alternatives by using digital games and immersive environments and give feedback based on this experience. Therefore, urban designers can control the consistency of their design solutions from the users' perspective.

5. Conclusion

Technology-driven urban design tools empower urban designers by (1) helping the decision-making process and enable reasoning, (2) producing a vast amount of design alternatives that would not be possible through traditional ways. As a result, these tools also assist designers in finding data-driven design solutions for complex situations. More people can participate in different participatory design actions through ICT-enabled participation tools. As a result, the role of urban designers has changed, requiring them to make decisions more collaboratively and possess a basic understanding of computational design elements to identify design problems and goals. They need to find new ways to integrate non-discursive data, e.g., unique characters of the urban areas that are not identified as metrics, or participation data, in the computational design process. In addition, they are also expected to examine the consistency of design output produced by computational design tools with participants' satisfaction and unique characteristics of designed urban areas based on their intuitive design ability as stated by Expert 2 in a personal interview.

Effective and inclusive urban design practices have faced challenges due to the lack of interaction environments that enable urban designers to collaborate with other expert groups in identifying design goals and creating design scenarios. Moreover, there has not been enough identification of how the participants' data and grounded values of the urban areas into computational design practices have not been sufficiently identified yet. Currently, the incorporation of non-discursive data into computational design practices is not well-established. Therefore, it is important to use a combination of intuitive design methods and computational power. As pointed out by Çalışkan (2017), instead of considering computational design tools as "Design Machine" they should be used as a "Design Support System" to empower urban designers to create urban areas in a more holistic, integrated and consistent way.

An overall conclusion, it is currently too early to effectively and inclusively make use of the full potential of technology-driven solutions in urban design practices due to several reasons:

- A lack of a comprehensive design ecosystem for data integration to extract meaningful insights
- Challenges in identifying specific design problems

- Potential inconsistencies in arising between the logic of computational design and participation data
- Limited application of technology's full potential in urban design practices

This study critically examines the paradigm shift in urban design practices in the digital age and projects the future components of the urban design process in a general way. The critical perspective and arguments presented in this study can be useful for future research. This critical discussion should be held regularly because the affordances and potentials of technology-driven urban design solutions evolve. There are limitations to this study. Firstly, it addressed the issues to some extent because it is based on declarative knowledge: computational design experts' experiences and previous research findings. Secondly, collaboration with urban design professionals was needed to carry out in-depth field studies like protocol analysis to document their reactions and experiences. Thus, our future research direction is to carry out an in-depth field study in collaboration with actual stakeholders to examine varying cutting-edge urban design tools and methods, document the actors' reactions, and propose key success factors for developing an effective and inclusive urban design ecosystem driven by technology for future practices.

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