Generative Urban Design for Smart, Sustainable Resilience Cities

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ABSTRACT

Cities today face major challenges in meeting sustainability goals, and they are growing at an exponential rate. Meanwhile the contemporary urban planning process is often viewed as a complicated and fragmented workflow. City officials, urban planners, designers and architects, often use disparate, unorganized, and time-consuming workflows, causing the urban planning process to take more time, effort, and money. Saudi Arabia has set ambitious goals to transform its cities into smart and sustainable cities by 2030, but to achieve this, we need to start implementing better workflows. The utilization of advanced technologies such as generative design tools can help us move from the traditional policy making framework to a more analytical and scenario driven process while enabling the collaboration between different stakeholders to help address future cities design challenges. There is a need for a more holistic urban planning process to coordinate efforts more efficiently and to make smarter planning decisions. For this reason, this research project aimed to explore the generative design framework and apply it to a local neighborhood case study, to see the applicability of this process in the Saudi context, and if this workflow can generate more optimized proposals that can help accelerate cities transformation. Autodesk's Spacemaker software was used in this study, to utilize the generative design workflow. Data has been gathered from the case study competition materials and from the site analysis conducted. The main results that were found includes, better building and parking configurations, sun exposure, noise reduction, better views, and wind indicators. Which signifies the importance of implementing the generative design framework for early-stage planning in order to accelerate cities performance to help achieve more smarter and sustainable cities.

Keywords: Sustainability; Smart Cities; Generative Design; Urban; Neighbourhoods

INTRODUCTION

1.1 Background

Half of the world lives in cities, and the UN predicts that the global rate of urbanization will reach around 70% by 2050 (United Nation, 2018). This unprecedented growth, encouraged and accompanied by unprecedented technological changes, presents a myriad of challenges and opportunities. Many people will live in cities built for much smaller populations with very different needs, built decades or centuries ago (Rauber & Krafta, 2018). The growth of these new metropolises risk making them sprawl, inefficient sinks that waste precious resources. Cities are also responsible for around 70% of Global GHG emissions (UN Environmental Programme, 2020), and the construction industry alone is responsible for around 70% of global CO_2 emissions (UN

Environmental Programme, 2020). Additionally, the construction industry is having problems with increasing its efficiency and productivity when compared with other industries (McKinsey Global Institute, 2017). Sustainable development asks how we can fulfill the needs of the present without compromising the ability of future generations to meet their needs (Graymore, Wallis, & Richards, 2009). Furthermore, city planning must allow for active participation by residents living and working in the city to gain their support (Reichental, 2020). The current process for the design of an urban master plan typically involves a team of architects and urban planners that conceive a handful of schemes based on zoning requirements with the help of CAD software with little to no public participation. Quantitative analysis are rarely conducted early and consistently throughout the design process which makes it difficult to understand the full range of optimal design schemes (Nagy & Villaggi, 2018).

Problem Statement

As cities continue to grow at an exponential rate, planners, designers, and developers are facing increasingly complex challenges and a bigger responsibility to design sustainable cities (Shen, Ochoa, Shah, & Zhang, 2011). Traditional city planning, and design cannot adequately navigate the complexity to solve urban problems across different scales. And for future cities to deliver on the quality of life, genuine collaboration is key, where all stakeholders communicate actively with each other (Reichental, 2020). According to The European Parliament (2014) Smart and sustainable cities promise to improve city life for everyone by utilizing urban technologies to handle urban concerns while also ensuring that it fits the economic, social, environmental, and cultural needs of current and future generations (Reichental, 2020). These cities are no longer a luxury but a pressing need in order to best accommodate rapid urbanization, and this new way of considering the city needs new approaches for city planning (Reichental, 2020).

Saudi Arabia has set ambitious goals to transform its cities into smart and sustainable cities by 2030, but to achieve this, we need to start implementing better workflows (Saudi Vision 2030, 2016). New urban technologies make it possible to take the planning, design, and making of cities to the next level and they can allow for active public participation (Nagy & Villaggi, 2018). Smart and sustainable cities are about people and not just technologies, where citizens communicate actively with each other but also have a vision for the city and where they live resourceful with each other. However, automation allows for the management of an ever-increasing number of variables and parameters that would be impossible to manage manually and can adapt much more quickly to changing city demographics (Wilson, 2021).

The whole process of designing buildings is inefficient and we need to identify a way in which they can try to address this problem by using new technologies, using Artificial Intelligence (Wilson, 2021). The pressure on the people who are designing the cities of tomorrow is getting more intense, if they are to realize the livable and sustainable cities that we need, they need new powerful tools (Reichental, 2020). Planning stakeholders need to be able to create, collaborate, and communicate key planning initiatives effectively and more specifically planning teams need tools to proactively build future scenarios, evaluate proposals in context and digitally engage with the public, and citizens should be able to get involved on their own time and be consulted on the projects that impact their communities (Wilson, 2021). Generative design tools take advantage of current computers' computational capabilities and allow designers to evaluate diverse and complicated options by automating design processes with algorithms (Nagy & Villaggi, 2018). These tools and data science can help us address future cities design challenges as well as allow for active public participation. Therefore, the purpose of this study is to see how generative design tools can help cities develop into smart and sustainable cities (Reichental, 2020).

1.3 Objectives

Given the need for a more advanced technological approaches in designing cities of the future, this study aims to show how leveraging generative design tools can help cities not only be smart but sustainable too How innovations in technology, planning, and sustainability assessments tools can help create smart, healthy, resilient and inclusive cities to improve quality of life. The main objectives of the research is to identify the generative urban design framework and its methods, to design and apply the method on a local neighborhood case study, to measure the performance of the proposal's outputs, and to compare the traditional method with the generative urban design method. Other objectives include; the encouragement of computational tools and analytics use in the Architecture, Engineering, and Construction (AEC) industry; the identification of the types of data needed to stream line the generative design framework; the quantification of the different design options and measure their performance across certain metrics; the conceptualization a collaboration to support participation in urban planning and development processes. The scope of this research includes; the utilization of local architecture and urban design competition and extract the needed data from them to be the utilized in the generative design model; the focus will be mainly on the neighborhood scale; the assessment of the design options performance and the selection of the best method; finally, exploring ways for data visualization and to different methods for active public participation and different stakeholders' collaboration.

1.4 Research Questions

To achieve the objectives mentioned above, the research questions below will help address these objectives and help the research project development while exploring the complexity of the generative design process.

- How can we utilize data and advance technologies to help us design more efficient cities that consider not only the needs of its residents, but also the impact they have on the world and its resources?
- What are the requirements to implement the generative urban design framework? What are its different methodologies?
- How can generative urban design tools help us design more smart and sustainable cities in Saudi Arabia?

LITERATURE REVIEW

2.1 Terminologies

2.1.1 Parametric Design

Parametric design can be understood as designing within a set of parameters. An easy architectural example would be a parametric façade that allows the designer to vary the height, depth, and number of panels by changing a set of input variables. Simply put, a "parametric" model is a set of inputs that can vary, a defined set of rules that interprets the inputs, and the resulting output of the rules (Stasiuk, 2018; Wilson, 2021).

2.1.2 Computational Design

Computational design can be understood as harnessing the power of the computer to do what it does best: compute large sets of equations to produce NEW data. Whereas a parametric design will explore the options made available by its inputs and parameters. A computational design returns analytical insights such as daylight levels, outdoor comfort, or floor areas. Simply put, a "computational" model is a parametric model that generates a new information about the performance of each option (Stasiuk, 2018; Wilson, 2021).

Computational model = Testing all options in a design space (Automation) (AI)

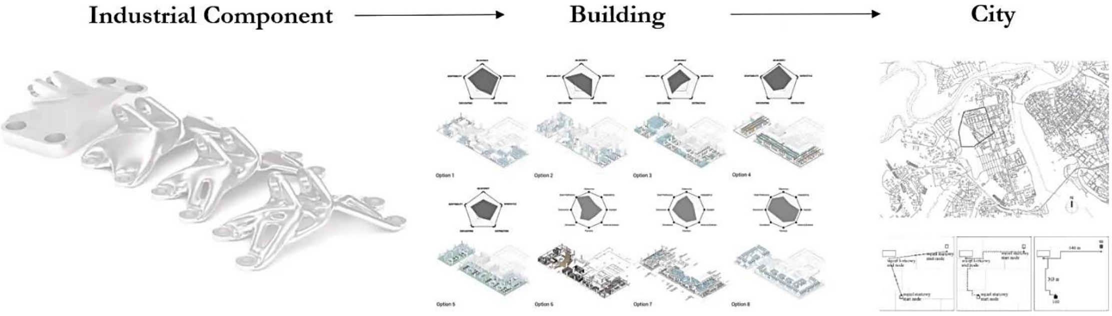
2.1.3 Generative Design

Generative design refers to a recursive process where an algorithm has a degree of autonomy, learning from one generation of results, and manipulating the inputs for the next generation in order to advance towards a stated performance goal. While generative algorithms typically evidence a greater degree of sophistication compared to computational systems, their logics can be both opaque, limiting a designer's agency in interpreting the data. Simply put, a "generative" model is a computational model that makes its own decisions about how to proceed through a vast selection of possible options (Stasiuk, 2018; Wilson, 2021). Furthermore, Autodesk defines generative design as "a technology that mimics nature's evolutionary approach to design. It starts with your design goals and then explores all of the possible permutations of a solution to find the best option. Using cloud computing, generative design software quickly cycles through thousands — or even millions — of design choices, testing configurations and learning from each iteration what works and what doesn't" and this process lets designers generate brand new options, beyond what a human alone could create, to arrive at the most effective design.

Generative model = Testing some options in a design space (Automation) (Machine learning)

Generative design is part of an open algorithmic framework for multivariate digital computation. Though the output goal differs between project to project, there is an infinite amount of data layers that can be engineered to solve issues related to street design, building layouts, and automated environmental reports. The generative design framework can be applied to a very diverse set of problems and at many different scales (figure 1).

Figure 1. Different scales of generative design applications.



Today, applications of generative design is well known within the manufacturing industry (Nagy et al. 2018) and computational design techniques have been successfully used at the building scale to test numerous designs and quantify their performance but are more challenging to apply at the urban scale due to increased computational expense, difficulty in limiting inputs, and more stakeholders involved in the process. A New Theory of Urban Design was one of the earliest iterations on generative urban processes. Christopher Alexander and his colleagues determined generative design by which the process is a sequential collaboration between series of participant cycles, unable to be bounded by a master plan. Alexander had this vision since the 1980's and with the help of generative design systems and evaluation metrics we are looking at a future where his vision will start to fully materialize.

2.2 Generative Design Framework

Professor and Architect Danil Nagy (2020) has defined the generative design process as a composition of three stages or components (figure 2):

- **Generation –** in which we delineate a 'design space' as a closed system which can generate all possible solutions to a given design problem
- **Evaluation –** in which we develop measures to judge each design's performance
- **Evolution –** in which we use evolutionary algorithms to search through the design space to find unique high-performing designs

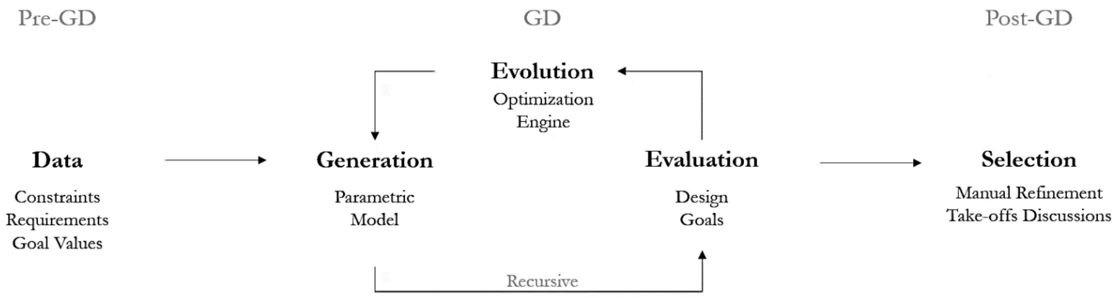


Figure 2. The three stages or components of the generative design framework.

2.2.1 Generation (Parametric Model)

After the pre generative design phase where all the project data are defined, the next step is to design the parametric model as a base for the simulation and optimization as a recursive or iterative processes.

2.2.2 Evaluation (Simulation)

In the evaluation phase using simulation tools, design goals are evaluated based on design objectives. Examples include (Sunlight exposure, wind, energy, views, etc.). There are different grasshopper simulation tools that are already a widely used (table 2).

2.2.3 Evolution (Optimization)

In the evolution phase the use of evolutionary optimization algorithms helps with identifying the most optimal solutions based on the parametric model and certain defined design objectives. There are different grasshopper optimization tools and this paper attempts to find and test the best ones in terms of performance (table 3). Lastly, in the post generative design phase, manual selection and refinement of the chosen optimal solutions.

2.3 Generative Design Applications

The generative design framework is already being used across different industries and their tools are being developed by various sized companies such as Autodesk, Google's Sidewalk Labs, Digital Blue Foam, Spacemaker AI and other competitors (Muñoz, 2021). Their applications range from manufacturing aircrafts, automobile, urban planning and design, architecture and construction, furniture, products, and jewellery design with the help of additive manufacturing technologies such as 3d printing (MIT, 2020).

2.3.1 Urban Applications

The role of computing has been identified in spatial planning and building design for managing complexity, enabling the design of advanced morphologies, by a performance-driven design approach (Asl et al, 2014). Urban planning and design have always been a difficult task because of the wide range of disciplines involved as well as the diverse set of stakeholders. The extended duration of the design/realization process adds another layer of complication to the equation. The use of generative processes in urban design, therefore, seems of obvious interest. Examples of urban generative design uses includes, optimizing cities walkability, and the layout of neighborhoods based on certain metrics such as optimum wind flow. Generative design tools in planning can generate billions of planning scenarios and evaluate the impacts of different scenarios on key quality-of-life measures (Daher et al., 2017). This holistic model can also be combined with other technologies to play out the different visions through visualization and simulation based on real data and see what the repercussions would be of a particular type of planning and the overall experience that an individual might have (Figure 3). Generative design and the use of data driven decisions, makes data that is usually very abstract to us become more tangible, which can facilitate citizens engagement in the planning and design of their cities. This methodology yields more sustainable benefits than implementations of standardized, siloed use cases, which often result in early successes that then become inconvenient or problematic for some stakeholders when scaled. In comparison to traditional planning methods, generative design technologies have the capacity to produce several complete urban design concepts with numerous data factors in significantly less time.

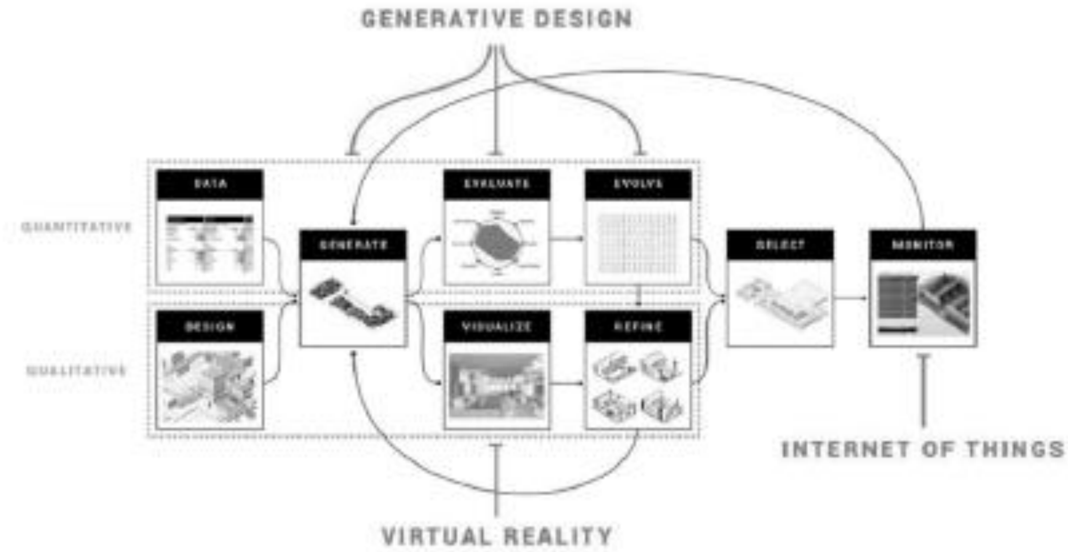


Figure 3. The Generative design method integration with virtual reality and IoT technologies, Kean Walmsley.

2.4 Multi-objective Optimization

In many real-life problems, objectives under consideration conflict with each other. Therefore, a perfect multi-objective solution that simultaneously optimizes each objective function is almost impossible. A reasonable solution to a multi-objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution. The use of some algorithms such as the genetic algorithm can help with the optimization of a multi-objective problem such as urban designing. The concept of genetic algorithms was developed by Holland and his colleagues in the 1960s and 1970s (Holland, 1975). Genetic algorithms are inspired by the evolutionist theory explaining the origin of species. In nature, weak and unfit species within their environment are faced with extinction by natural selection. The strong ones have greater opportunity to pass their genes to future generations via reproduction. In the long run, species carrying the correct combination in their genes become dominant in their population. Sometimes, during the slow process of evolution, random changes may occur in genes. If these changes provide additional advantages in the challenge for survival, new species evolve from the old ones. Unsuccessful changes are eliminated by naturals election. The genetic algorithm in well suited to solve multi-objectives optimization problems because it is a population-based approach. The ability to simultaneously search different regions of a solution space makes it possible to find a diverse set of solutions for difficult problems with non-convex, discontinuous, and multi-modal solutions spaces. In addition, most multi-objective genetic algorithms do not require the user to prioritize, scale, or weigh objectives. According to Autodesk, the generative design process includes define (goals and constraints), generate (design synthesis), and explore (interaction and decision making). It is a whole ecosystem where in define and explore it is the designer's perspective, while generating the options is the computer's perspective (Autodesk, 2018). In general, Generative design is a type of co-design that combines artificial intelligence with human creativity to come up with answers to design challenges that would otherwise be impossible to solve without a computer (Autodesk, 2018). Three primary processes are involved after gathering the data (Figure 1), the generation portion, which is a parametric model that may generate a large solution space, the evolution portion, which uses genetic algorithms that is based on principles of evolution, includes the employment of an intelligent system that can learn how to enhance each design solution across generations to increase performance, and lastly the evaluation portion, where the wining evolution picks the best high-performing solutions (Autodesk, 2018). The human component is always present in the process but specifically at the beginning during the input of data, goals and constraints, and at the end once we have this large data set of design options, we can then start to navigate the design space and through custom analysis tools identify the trade-offs between each design solution along the design goals that we have pre-established at the beginning of the process (Autodesk, 2018).

2.5 Active Public Participation

"Citizen", "community", and "public" are used interchangeably with "involvement", "engagement", and "participation", and they all fall under the same concept definition. They are umbrella terms that describe the activities by which people's concern, need, interest, and values are incorporated into decision and actions on public matters and issues (Nabatchi & Leighniger, 2015). The exact definition and interpretation of the concept vary between academic and practitioners but to put it simply, it is the acts of sharing of information, power, and mutual respect between goverments and their citizens (Al-Naswari, 2019). In urban planning, public participation is the process that serves the public and answers their visions, needs, and interests by providing a healthy environment in terms of location of their activities, appropriate space design, and appropriate social space, etc (Alshihri et al., 2020). There is a spectrum of the involvement of public participation in cities urban planning and design projects, and there are different methodologies and tools to conduct these participations (Al-Naswari, 2019). Researchers and practitioners of urban planning have had interests in developing and applying methods of public participation since the 1960s. Despite this, interest in methods have only recently been accelerated and a growth of a more holistic approach to public participation has been exemplified (Alshihri et al., 2020). Traditionally, public participation meant to gather knowledge in public events such as town halls or city halls. However, the conventional methods are not sufficient because, for example in terms of engagement, only a handful of the public participate, and they are not representative of the whole population. Additionally, citizens might find the timing of these public events inconvenient, or they might not feel safe attending in person because of Covid-19 pandemic fear still lingering to some (Bouregh, 2022). Alternatively, new methods and tools have been developed to help tackle this particular issue and to get a larger number of citizens to participate in these events. Goverments at all levels are now supporting a more active form of open public participation to help improve better, more sustainable urban planning decisions (Nabatchi & Leighniger, 2015). Nevertheless, planning teams need better tools and more advanced technologies to get the myriad benefits of open active public participation and to help facilitate community engagement more efficiently. Real-life practical applications in cities have only recently been integrated in practice with the help of newly developed software's in the cloud such as in the case of the recent ESRI's cooperation's ArcGIS Urban tool and even augmented and virtual reality tools.

2.6 Web PPGIS

Web Public Participatory Geographic Information Systems (PPGIS) encourages public participation in urban planning and development using GIS on the web (figure 4). It implies the inclusion of citizens who have been excluded from urban projects (Munkherjee, 2015). The goal of these projects is to make GIS technologies available to the general public in order to enhance their capabilities to generate, manage, analyze, and communicate spatial information (Tang & Waters, 2005). This is a standalone objective of PPGIS, to open up such specialized use of technology to the participation of citizens with little or no GIS training. The online applications allow for rich user interaction with a dynamic web as opposed to static, to empower local groups through demand-driven applications of GIS. Furthermore, in Participatory GIS there is a promotion of citizens intervention in decision-making processes, hence calling it Public Participatory GIS (Munkherjee, 2015). Applications include the protection of traditional knowledge and wisdom by local/indigenous groups, and the systemization of local spatial knowledge via basic community mapping and sketch mapping. The key point of Web PPGIS is that it empowers local groups to do their own GIS work, taking the power out of the hands of the GIS practitioners and giving it to the actual stakeholders, the people that are going to be impacted by the GIS work and allowing them to be in control of it themselves (Tang & Waters, 2005).

Urbanization challenges cannot be addressed without an active private sector. There are a variety of models for these partnerships in which participants take on different roles regarding initial investment, maintenance costs, management, ownership and other considerations. The most common is the Private-Public-Partnerships (PPP/3Ps) model, and they are an indispensable asset for infrastructure projects. However, experiences of the PPP model in last decades shows that they have not been able to fulfill desired objectives and have only partially addressed key issues (Kumar, 2015). Even government officials themselves are not confident of such initiatives and thus fail to deliver to unrealistic goals. Invariably, in the whole process of planning and implementation, beneficiaries or people are not involved in the urban projects and are usually an afterthought in the process (Kumar, 2015). Consequently, there has been a rise of a new model, the Public-Private-People Partnership (PPPP/4Ps) model, which is a people (end-users) oriented approach where all stakeholders including government, donor agencies, private sector and civil society work together.

Consequently, there has been a rise of a new model, the Public-Private-People Partnership (PPPP/4Ps) model, which is a people (end-users) oriented approach where all stakeholders including government, donor agencies, private sector and civil society work together. It is a new concept to bring public and private actors and the public together (figure 4) which includes the end-users' perspective into the Public-Private Partnership (PPP) model. The current worldwide practices have demonstrated and underscored possibility of potential new partnerships with people, stressing the need to valuing people in the implementation of public services. The new model offers infinite possibilities in unlocking potential of their use for innovation in the practices of public services delivering, within an urban innovation engine (Kumar, 2015). Where Administration through central or state government schemes and local bodies like municipalities should be able to tap vast potential of innovative and creative human social capital as self-contained model of growth for balanced development by community participation recognizing people power to organize, identifying aspirations of people, collaborate with people as partners. Thus, there is a paradigm shift from looking at people as users centric only to co-designers or active partners for desired outcomes, after all “cities are of people, for people, and by people” (Kumar, 2015).

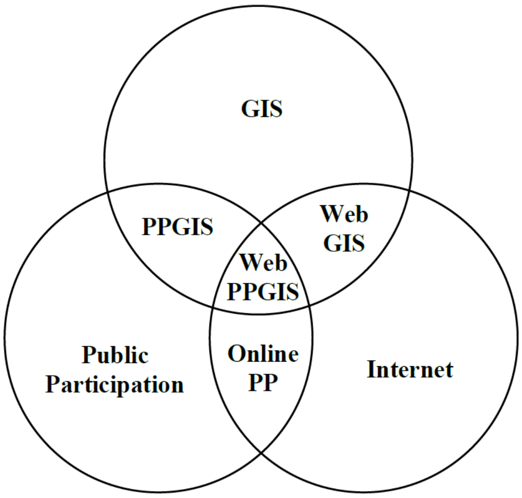
Figure 4. GIS, public participation, internet, and their integration. (Tang & Waters, 2005).

METHODOLOGY

3.1 Overview

This paper will discuss and demonstrate the use of a generative urban design framework at the neighborhood scale. And rather than have the project be applied on a hypothetical scenario, it would be best to apply it on a real project scenario in the region. Throughout the year, several architecture and urban design competitions are held in Saudi Arabia. The Samaya neighborhood competition was launched in 2021 in Al Khobar city https://twitter.com/samaya_2030 and will be the subject of this research. From this competition I will collect and analyze the data necessary to apply the generative urban design framework after studying which methodology is the best at addressing the urban design challenges proposed. There are several different approaches one can take in regard to the generative design framework and in the next paragraphs I will discuss and compare them. But in general the methodology consist of four steps: 1) Simplified Input Definition 2) Procedural Geometry Generation, 3) Performance Evaluation and 4) Analysis & Communication to generate and test multiple master planning scenarios.

3.2 Method 1



There has been an influx of several generative design companies in recent years. They all vary in funding, mission, development, and popularity but share the same vision where they make generative design tools very compelling and promise an easier entry approach. But these software development companies often oversimplify the generative design process which does not tailor to the project's unique characteristics (table 1).

	Company	Year	Location	Data providers	'Smart city' initiative plans
1	Sidewalk Labs Delve	2020	US	Google	Waterfront Toronto Initiative
3	Esri ArcGIS Urban	2019	US	Esri	City of Charlotte, NC
2	Spacemaker AI	2016	Norway	Autodesk	n/a
4	Digital Blue Foam	2019	Singapore	n/a	City of Shanghai City of Singapore Bogota, Colombia
5	Girraffe.build	2017	Australia	n/a	n/a
6	Archisat	2019	Australia	n/a	n/a
7	Parametric Solutions	2020	Sweden	n/a	n/a

8	[Kreo](#)	2017	UK	n/a	n/a

Table 1. Comparative analysis of 8 generative design software companies.

I will be using Autodesk's Spacemaker software in this research, which is the world's first commercial platform that uses artificial intelligence to help architects, urban planners, and developers, make better decisions faster.

3.3 Method 2

The other method is using common AEC industry software's such as Autodesk Revit and Rhinocersos 3D. These coupled with their own graphical programming interface and several plugins enable the making of a generative design model. After testing both software's to see their capabilities, I decided to stick with the Rhinoceros 3D software with its Grasshopper graphical programming interface and use plugins such as Ladybug for the simulation part whereas the use of the Discover plugin will be during the optimization phase. The choice was made after seeing the powerful computational capabilities of 'Rhino' and seeing how it was favored in the generative design community with a lot of resources online. In chapter 5 (Generative Design Framework) I discuss more about the process of making the generative urban design model used for the case study of this paper.

	Butterfly	Dragonfly	Spider	Eddy	Archisim	Urbano
	★★★★☆ (414) 455501	★★★★☆ (414) 455501	★★★★☆ (414) 455501	★★★★☆ (15) 7345	★★★★☆ (9) 10214	★★★★☆ (23) 9055
	Ladybug	Ladybug	Ladybug	Eddy3d	Timur	Timur
	2018	2020	2018	2020	2014	2019
		x				
					x	
			x		x	
			x			
		x				
	x			x		
	x			x		
	x	x				
						x

er simulation plug-ins.

Optimus	Opossum	Biomorpher	Wallacei	Design Space	Discover
★★★★★ (16) 2704	★★★★★ (37) 8710	★★★★★ (22) 8152	★★★★★ (61) 19050	★★★★★ (31) 4426	★★★★☆ (8) 755
Optimus team	Thomas Wortmann	John Harding	Wallacei trio	Digital Structures	Danil Nagy
2019	2016	2017	2019	2017	2019
x	x	x	x	x	x
x	x	x	x	x	x
					x
					x
x		x	x	x	x
					x
					x
jEDE		IEA	NSGA-2		Genetic Algorithm

Name	Ladybug	Honeybee
Rating	★★★★☆ (414) 455501	★★★★☆ (414) 455501
Creator(s)	Ladybug	Ladybug
Year	2018	2018
Climate Analysis	x	
Energy Modeling	x	x
Daylight Analysis	x	x
Shadow Analysis	x	
Renewable Energy	x	
Urban Heat Island	x	
Wind Analysis	x	
Occupant Comfort	x	x
Outdoor Comfort	x	x
Urban Mobility		

er optimization plug-ins.

Name	Rating	Creator(s)	Year	Multiple inputs	Input type: float	Input type: integer	Input type: permutation	Multiple objectives	Crowding distance	Constraints	Algorithm
Galapagos	NA	David Rutten	2013	x	x						
Octopus	★★★★☆ (53) 42608	Robert Vierlinger	2012	x	x			x			SPEA-2/HypE

CHAPTER 4
RESULTS

4.1 Site Selection

As mentioned in the methodology, the selected site is from the Samaya neighborhood competition inaugurated by the eastern province municipality (Emara Sharqia) and a collaboration with Saudi's ministry of housing, specifically their

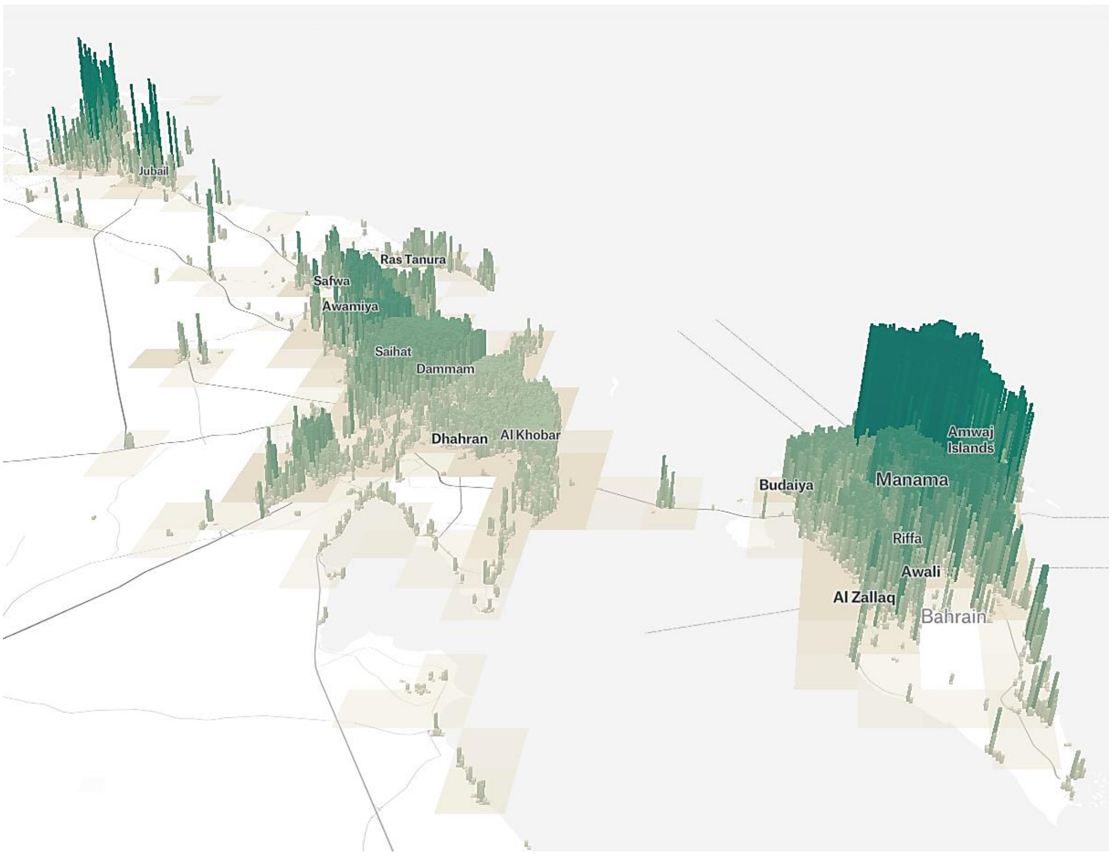
developmental housing program. The selected site is a rectangular land (figure 3) with an area of around 125,000 square meters located in the southern part of Al Khobar Saudi Arabia. The location of the site is pretty far away from the cities downtown and is missing a lot of the basic amenities services and is located next to several tourist attraction and resorts that are clustered in the eastern side next to the gulf's beach.

Figure 5. Samaya case study location in Al Khobar, Saudi Arabia

4.2 Data Collection

Most of the data is collected from the competition brief such as design requirements (figure 5) and any other additional materials provided by the competition organizers such as the zoning codes of the area. Additionally, some site analysis materials were collected from field observation and virtual site analysis, data such as population density (figure 4), wind directions and others were helpful inputs for building the generative design model. From the competition brief, the required neighborhood type requested is mainly a residential and mixed-use neighborhood type. All data were collected and transformed into a parametric format that the generative urban design model used to drive the form making of the samaya neighborhood design options.

Figure 6. Eastern region and Bahrain's population density map .



المساحة / م^2	النسبة	البند
125,000.00	100%	المساحة الإجمالية للمشروع
75,000.00	60%	المساحة المخصصة للتطوير
50,000.00	40%	الطرق والخدمات والمساحات المفتوحة
15,000.00	20%	الاستعمال المختلط Mixed Uses
60,000.00	80%	الاستعمال السكني Residential Use
6,000.00	40%	صافي مساحات الاستثماري المصرح بالبناء عليها
36,000.00	60%	صافي المساحة السكنية المصرح بالبناء عليها

المساحة البنائية / م^2	عدد الطوابق		البند
9,000.00	1.50	6,000.00	الاستعمال المختلط (تجاري : أرضي + ميزانين)
6,000.00	1.00	6,000.00	مكاتب (الطابق الأول)
15,000.00			**إجمالي الاستثماري**

أنواع الوحدات السكنية

المساحة الطابقية / م^2	عدد الوحدات	عدد قطع الأراضي	عدد الوحدات / قطعة	مساحة الوحدة / م^2	البند
900	216	12	18	150	عمارات نموذج (أ) 6 شقق / الطابق
800	162	14	12	200	عمارات نموذج (ب) 4 شقق / الطابق
120	120	120	1	240	دوبلكسات متصلة
	498	146			**إجمالي السكني**

Table 4. Tables from competition brief specifying design requirements.

4.3 Data Analysis

Design problem:

Goal	Generate an urban master plan that addresses Sharqiya's urban issues by incorporating more green spaces within the city and a greater homogeneity between the blocks that comprise the urban fabric.
Objectives	. High population density
	. Greater block connectivity
	. Minimal overshadowing of open spaces
	. Sufficient open space
Fitness Criteria	. Maximise density within the neighborhood
	. Maximise connectivity between adjacent blocks
	. Maximise courtyard sizes
	. Maximise solar exposure on ground level
Phenotype	Series of residential blocks with mixed-use areas
Gene Pool	. Number of building units within the block
	. Size of main block courtyard
	. Size of inner unit courtyard
	. Number of floors per unit
	. Number of sides per block
	. Size of buildings

Evolutionary matrix:

Fitness Criteria	Genes			
	Building Area	**Courtyard Area**	**Building Height**	**Communal Garden**
Increase Open Space	✓	✓	**X**	✓
Increase Density	✓	**X**	✓	✓
Increase Wind Flow	**X**	✓	**X**	**X**
Increase Sun Exposure	✓	✓	✓	**X**

Design Intentions:

- **Mixity** – to create and manage land use diversity.
- **Connectivity** – to create a good user walkability experience.
- **Green public space** – to create a balance between private and public spaces.
- **Energy efficiency** – to drive the design through solar occlusion parameter.
- **Density** – to create a compact and connected urban environment.

4.4 Design Analysis

What I have done is input all of the data into the Spacemaker platform and then the system starts processing billions of possibilities and returns detailed layouts of the best possible options. The Samaya neighborhood site in the Spacemaker software imposed with a layer from the Eastern Region Municipality’s geographic portal for zoning code (figure X).

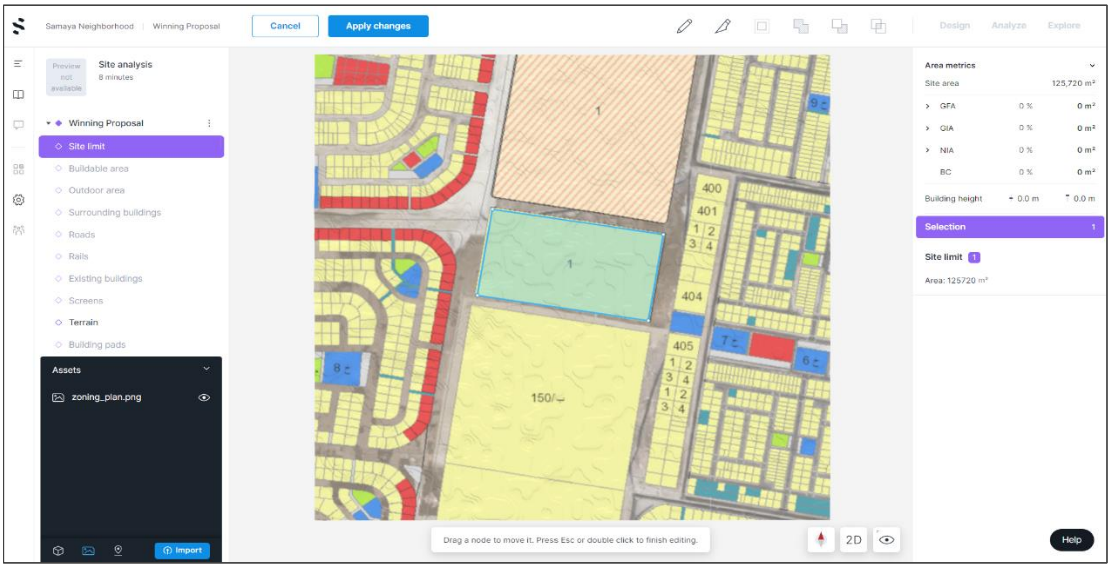


Figure 7. Eastern Region Municipality's geographic portal for zoning code layer on Spacemaker.

Figure 8. Traditional Method Model.

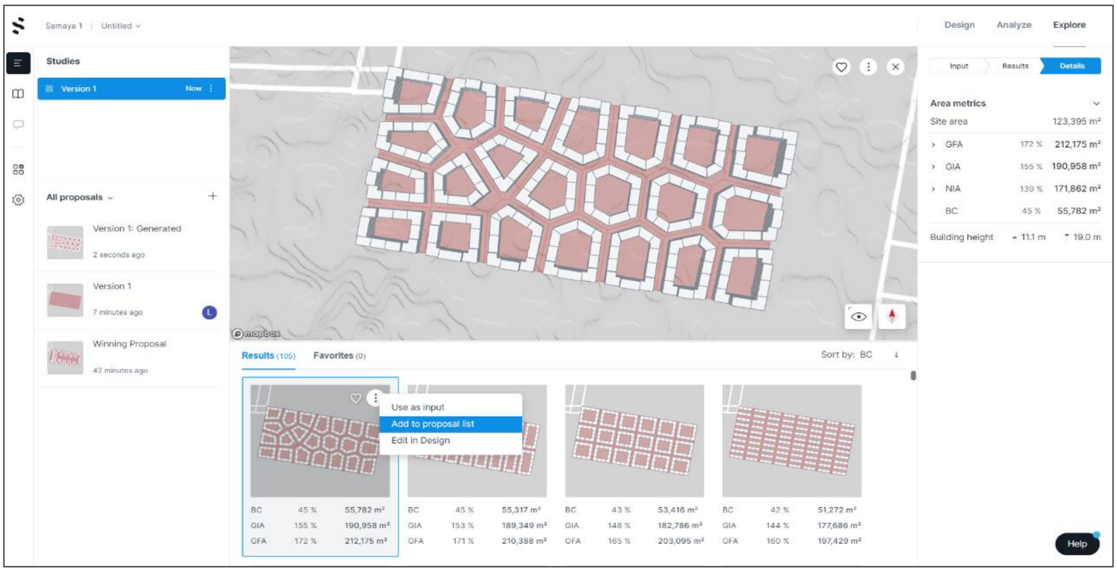


Figure 9. The Generation Process.

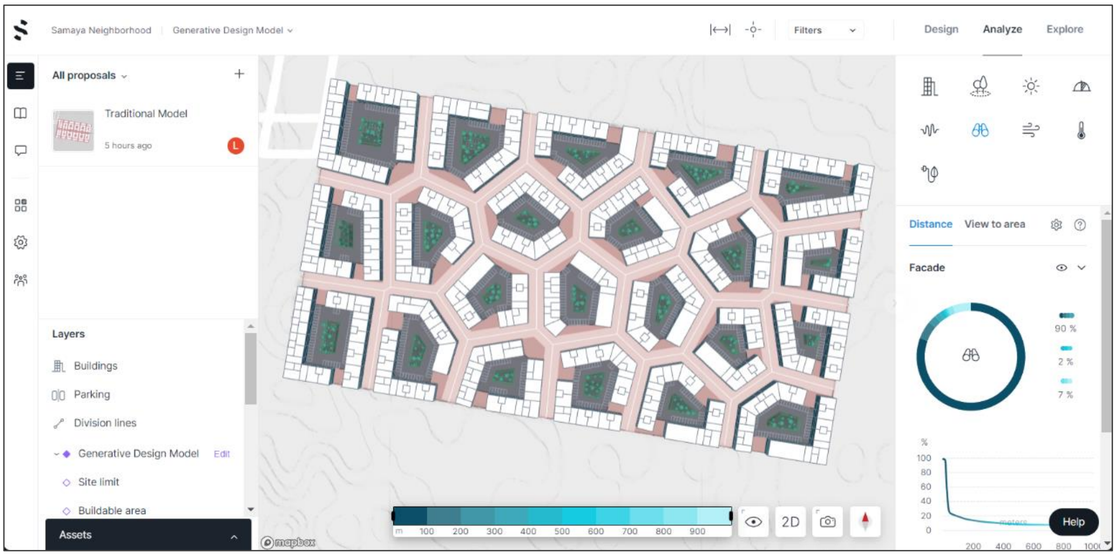
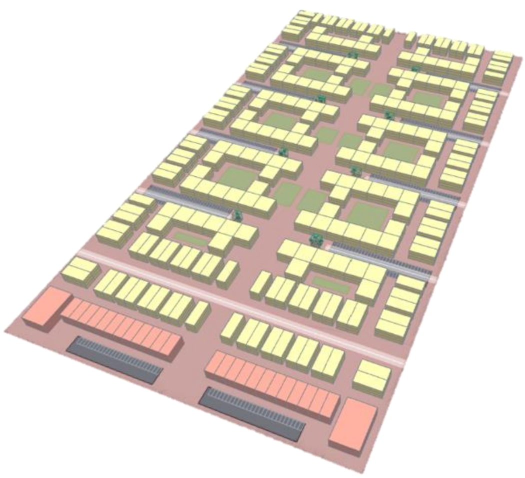


Figure 10. Generative Design Method Model

<u>Building and Parking Configuration:</u>



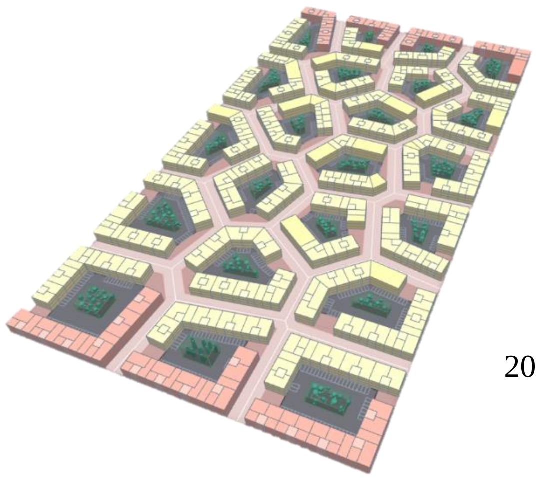


Figure 11. Building and Parking Configuration. Traditional (left) Generative Design (Right).

Solar PV (Energy):

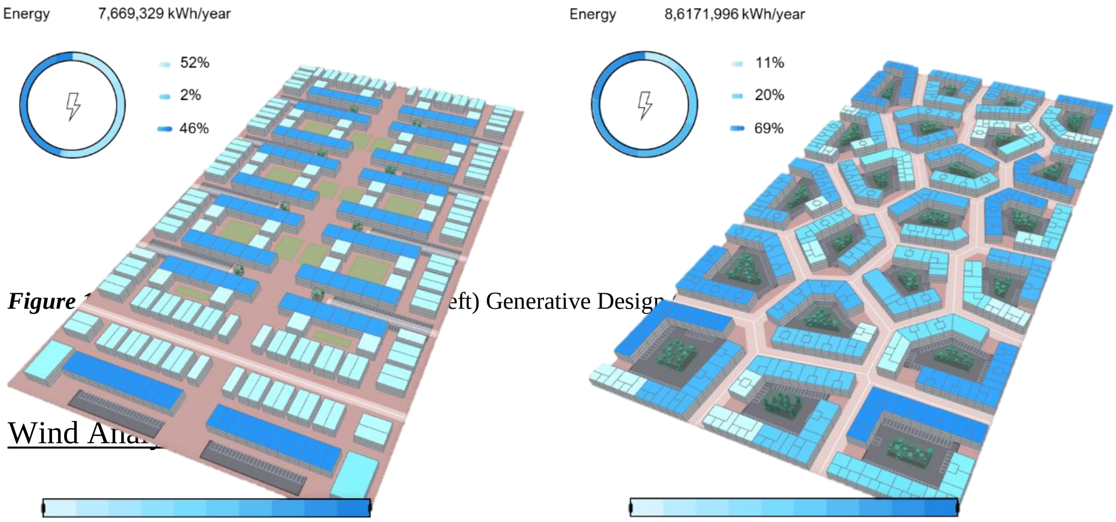
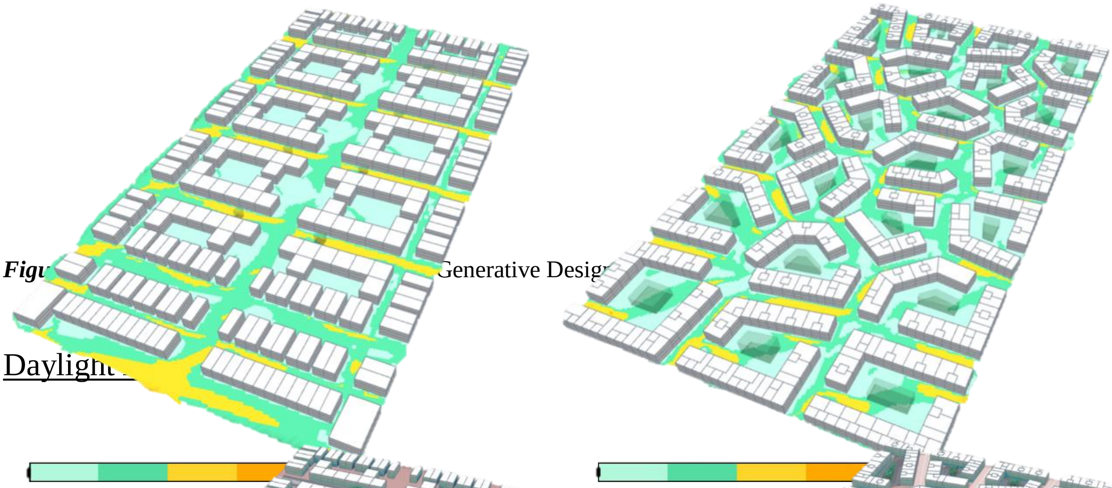


Figure … eft) Generative Design

Wind Ana…



Figu … Generative Desig…

Daylight…

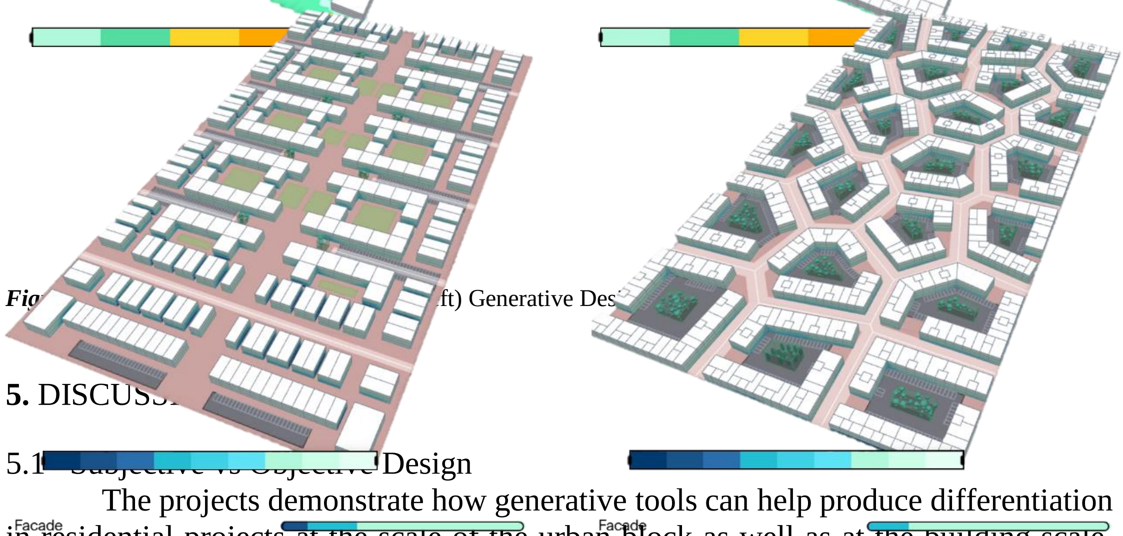


Fig … ft) Generative Des…

5. DISCUS…

5.1 … Design

The projects demonstrate how generative tools can help produce differentiation in residential projects at the scale of the urban block as well as at the building scale, while managing the complexity of each project in relation to their performance criteria and goals. The design proposal of the neighborhood incorporates a range of public spaces suitable for a variety of social and commercial activities. A challenge of this papers methodology that requires further work is the relationship between form and performance. At the building scale, if you change height, orientation, or location, the link to the resulting performance is clear. At the urban scale, performance is being analyzed across a heterogeneous urban fabric. This means different parts of the masterplan can perform differently. When you distill the analysis of the master plan to a single metric, most of this variation is lost. Further development of analysis tools will focus on addressing the spatial distribution of the performance evaluation. Because the process is composed of algorithms, it would be a mistake to think that its unbiased. The range of values supplied for inputs could exclude certain possibilities that might be desirable to some stakeholders. One solution to limit bias is to provide a much larger range of options in terms of the inputs and logic upon which the model is built. Another solution is to solicit specific inputs from all stakeholders since this methodology allows for manually generated inputs. The potential for bias also illustrates the need for design and judgment in the process and the active engagement in with stakeholders so that, while not every option is explored, the critical ones are represented.

5.2 Advantages and Opportunities

Large scale master planning takes days, weeks, or even months to create a single option, and computational generative design tools strive to rapidly prototype the design process. More importantly, we can start engaging the public and other stakeholders in the planning and design of their cities through visualizations and simulations to get their solicit feedback from a broader audience. City Planner and Geographer Evan Lowry argues that generative design iterations can help the community visualize how a place would look like before shovels go into the ground, and for the planning process, cities can use visualization software's powered by the generative design framework for communities to visually experience their cities developments. Residents instead of attending community centres, they can just pull a website and turn layers of and on to see how different city developments relate to their own house and neighbourhoods, which will help with the community engagement (Lowry, 2020). Community members can give their feedback online instead of traditionally attending meetings at government centres or somewhere in the community which has become more difficult to do after COVID-19 pandemic. Online virtual engagement will have the opportunity to reach more people, more accessibility, and more meaning. Future planning and designing could be more interactive between all stakeholders.

The construction industry struggles with efficiency, and it needs to embrace technology to improve it. According to an article in the Economist magazine titled "Efficiency Eludes the Construction Industry", it showed the change rate of value created per hour worked in various industrial sectors over the last 50 years. The graph (Figure 5) shows that the efficiency rate of the agriculture, manufacturing, wholesale and retail industries has all skyrocketed, except for the construction industry, where peaked in the late 60s and has gone down ever since, back to its baseline of 1947.

Furthermore, Dr. Crayton Miller of National University of Singapore, in his course "Data Science for Construction, Architecture, and Engineering", argues that a huge amount of data is being generated every day in the Architecture, Engineering, and Construction (AEC) industry, from buildings, neighbourhoods, and districts and that we need to start turning them into useful information. He further states that data science is an important field for the built environment industry, because of all the big challenges that it faces when it comes to efficiency. When it comes to data analysis in the AEC industry, Dr. Miller believes that there is a key challenge that impedes improvements in efficiency, this challenge is that the design of buildings is mostly different with each one being a one-of-a-kind prototype, and we have different teams of architect's engineers and contractors who are designing, constructing, and operating buildings in completely different ways. It is difficult to achieve the same economies of scale that occur in other industries when each of the products is customized. He then recommends that building professionals need to develop their analytical skills, to analyse datasets from different sources. This means that ad hoc analysis and adaptive automation are more crucial now than ever, to start improving the industry's efficiency rate (Miller, 2020).

5.3 Disadvantages and Limitations

There is a perception that machines will take over the human (designer) jobs. The role of the designer will change but generative design is only a framework that can help free the designer from their own biases so that we do not neglect important parameters such as sustainability, which often gets neglected in the traditional framework. It is more of a collaborative effort, which means that their need to be people who understand both domains, who are interdisciplinary in both the design and computer science fields. Knowledge domain is certainly needed, the collaboration is a whole ecosystem that is iterative. Their needs to be some kind of training for highly qualified specialists in the field of information technology in relation with urban design. Some other criticism state, that computers can never replace the human creativity process but that is not the goal of the generative design tools to replace humans at all, what it does do is, it only creates insights that we humans are sometimes kind of formatted not to explore, so the computer will explore the space in a way that we will not necessarily do ourselves and generate solutions that inspire us to think about the problem differently as well. Generative design will give us insights that are outside of the norms of what we would generally decide to do. Information processing is only one aspect of urban intelligence.

Shannon Mattern, in her article titled "The City is not a computer", contends that data-driven models that delegate often ethical judgments to machines should be rejected. And that we must understand the flaws in models that assume the objectivity of urban data. She states that we as humans, create urban knowledge through a variety of methods, including sensory experience, long-term exposure to a location, and carefully filtering data. Making room in our cities for those many types of knowledge generation is critical. And, as part of all planning and design processes, we must consider the political and ethical implications of our methodologies and models. We need to look at data in context, at the lifetime of urban information, which is disseminated throughout a diverse ecosystem of urban locations and people who engage with it in a variety of ways (Mattern, 2017). She believes that city-making is always, concurrently, an enactment of city-knowing, which cannot be reduced to calculations and that it cannot be reduced to algorithms. I personally agree with her view, although I cannot help but to think if there is an in between solution, where we can combine both the objective and subjective aspects of urban design in the early stages, and that maybe generative design tools can help us reach there?

5.4 Will Generative Design replace architects?

Of course not, AI will never be able to integrate all the thinking and idea creation of an architect. It is however, a tool at the service of the architects, in the form of an assistant. It necessitates the collaboration between the architect and machine. It is always the human that makes the decisions, but they will be helped by the computation power of the AI. It will allow the architects to be challenged in their many choices, but they will not be replaced. However, the role of the architect could change from a single mastermind to that of a process designer, collaborating with stakeholders, consultants and computational tools. These tools makes architects even more effective than they are today, because they can start answering all of the questions that are hard to answer for humans and it requires computation to enable them to focus on the creative side. With AI you can enable the architects to get a very fast feedback on what they are doing, and that is very important because the faster the iterations are, the faster you can process new designs, the more ideas you can explore.

5.5 Expanding Public Participation Methods

Participation is an approach in urban planning, and it means being part of decision-making, holding others and the government accountable, and being an agent of change. Historically, voting, town hall meetings, and committees have been the dominant mechanisms of public participation. Voting is the most obvious tool of engagement, but its infrequency and the choices it enables are limited. Town hall meetings; despite being neither restricted to towns nor necessarily held in town halls; are a favorite for cities worldwide. They are essential part of how cities function and how individuals can participate in their city's operations. Typically held in person, a town hall meeting has some main functions including, providing a meeting place for elected officials and community, acting as a forum for community members to raise and discuss issues, serving as a space where legislation, regulations, projects, and budgets are discussed, considered and acted on, and offering a place to share information of relevance to elected officials and community. Though town hall meetings are still mostly held at physical locations, increasingly it is possible to attend remotely, and more sophisticated cities enable remote participants to talk or interact electronically with the meeting. But times have changed and in the digital age a much broader set of channels and forums have become available.

A few new ways that technology is supporting increased public participation includes, social media channels, online discussion platforms, civic apps, open data portals, events such as hackathons or urban challenge, texting, and survey and polling tools. Though traditional analog forum methods are able to capture the participation of those who are prepared to show up in person (a diminishing number), they provide a narrow option for broader engagement. Digital tools, have the ability to cast a much larger net of participants. In addition to convenience, these tools have become a 21st century expectation of city democracy. That expectation must be met by city leaders who embrace these channels, provide support for them, ensure that posted content is shared with the right people, and educate the community on options and use. To be considered an inclusive city, all residents need to have a channel open to them. More voices mean a stronger, more informed, more engaged, and more vibrant democracy. A smart city demands increasing active public participation. The goal is to ensure that the results of a design effort reflect participant needs and preferences. Together, everyone helps to define the problem to be solved, explores solutions, and then assists with making the decisions about what direction to take. Evidence indicates that engaging many perspectives in the design process results in a more innovative outcome.

5.6 Smart and Sustainable Cities

In the smart city environments, “urban processes, citizen engagements, and governance unfold through the spatial and temporal networks of sensors, algorithms, databases and mobile platforms” (Gabrys, 2014). This new way of considering the city implies new approaches for city planning which should contribute to its resilience. The application of computational design is increasing in the Architecture, Engineering and Construction Industry. "Parametric Modeling" reflects recent trends in computing design in academic research as well as in market innovation. It allows the designers to control the generation of visualized 3D objects from an overall logical computing script or scenario (Davis et al. 2011). At the urban level, computing brings a lot of opportunities to designers and developers, e.g. in simulating the impacts of land uses, estimating urban development strategies or enabling involvement of citizens in decision-making. Openness, interoperability and integration of multiple datasets remain key challenges in the development and exploitation of such tools. Urban components share a similarity that can be defined parametrically. Aspects such as density, functions, forms, and spaces, can be translated into parameters. This approach helps in evaluating different scenarios and enables to reach an optimum solution. In addition, the usage of a parametric approach in urban design can lead to a sustainable result (Saleh and Al-Hagla, 2012). For example, the planning authority of a project can make designers change the design overnight, and that is when you can see the real value of using generative design tools. Making such change architecturally and engineeringly and making sure that it actually works, normally would take easily a month, but with generative design tools such as Spacemaker, we are able to fundamentally within a day make these changes. Importance of computation in urban planning. Students need to be prepared for this new technological reality when they enter the real world. Universities such as MIT are offering new degrees such as Urban science and planning with computer science where the requirements are one-to-one urban planning theory and computer science techniques because they believe that if they do not have that literacy, they are not affective arbitrators of the urban environment. The future of AI is to be integrated in everything we do.

A city leader’s main responsibility is to embody and promote public interest on the path to development. In doing so, he or she has to make lasting decisions that enhance the quality of life within the city, and that do not create negative impacts outside of it. Building and developing the basics of life which contribute to increasing the rate of satisfaction, and promote it for the individual and society, which include infrastructure, public decency behaviors, the visual scene, the humanization of the cities, traffic safety, public parks and roads development, and all other stuffs related with raising the quality of life in the cities. As planners we are all challenged by uncertainty, for example with extreme climate events becoming the new norm we are forced to reevaluate how we are planning for the future political shifts and economic events. What if the next generation preferred a mode of transportation that is something we would have never imagined five years ago, our cities are changing rapidly driven by factors such as climate economics and technology. But our normal 5, 10, and 20 year plan updates and static documents are not always capable of capturing and responding to the changes particularly not when they are based on a single projection of the future. In addition to that, it’s hard for planners to communicate the trade-offs related to complex issues and to help communities see their options and choose a path forward. Community input is key, and too often we see singular loud voices dominating the conservation. This contributes to a lack of the diverse representation of community input that most planners are striving for. So, we need to seek new ways to reach new demographics so that we can plan for everyone.

CONCLUSIONS

6.1 Overview

In conclusion, while cities are a great challenge for us, if we can utilize the right smart solutions and technologies, it can help us with the journey of transformation into smart and sustainable cities. Generative design tools are still not perfect, but despite that, it still has powerful capabilities to change the filed of urban design entirely. At the end of the day, it is only a tool, and when designing smart and sustainable projects, we should always keep in mind the community's engagement in the city because none of the smart solutions will work without them. Barcelona is at the stage where it can have a more citizen centric vision after the success of their technological centric vision, and Saudi cities can hopefully do the same. While it might be more challenging for Saudi cities to catch up with other smart cities, the utilization of generative design tools might help fast-track their development and introduce the citizen centric approach at the early stages. However, in order to achieve that, more awareness and training are needed in Saudi Arabia's universities and design firms need to adopt new innovative and sustainable business models. This paper described the implementation of a generative design workflow at an urban scale through the design of a residential neighborhood in Al Khobar, Saudi Arabia. To measure the success of the generative design workflow and each of its design options, some metrics were chosen to distinguish the best options and methods. Additionally, the final chosen generative design model were benchmarked with the designs of the 3 top winning proposals to compare their performances and to see the applicability of the generative design workflow. This research shows how the generative design process can generate good design strategies leading to a better and more informed final design. Although the results of this project have been encouraging, the application of Generative Design to the urban scale requires further research and testing. Future opportunities include the integration of additional design metrics that are critical for planning at an urban scale such as user comfort, safety, and traffic. These metrics can expose even more of the complexity of urban design to the Generative Design process, leading to design solutions which are both highly functional and go beyond the intuition of human designers alone.

6.2 Recommendations

Whether you are an architect, urban planner, or real estate developer, the generative design framework can help you design better cities. Generative design tools will revolutionize urban site planning and design. Especially for early stage planning. AI can bring a more holistic approach to understanding architecture and uncoding its complexity in terms of computer commands. We are in the turning point where large actors in the field want to invest in AI, want to understand what is happening. City planning should be multidisciplinary, and we must begin a dialog with AI for architecture and architects. Traditionally that tools we are using are very simple, we are starting the transformation right now, and it is very exciting. When we combine architecture institutions with artificial intelligence and give the architects superpowers. The architecture process will not be dramatically changes, but it will be heavily influenced based on AI. So you can drastically reduce the time spent on heavy calculations, and change that into an even deeper creative process, getting into higher highs, but with less risk. And that is where math and computers, can really support that relationship, because you can really prove that the design choices made has a positive affect to the project. Saudi cities leveraging generative urban design tools will help tremendously with their transition into smart and sustainable cities. Effective public participation in urban planning can help us make better informed decisions, raising the quality of life, and level of satisfaction in cities as well as avoid devastating urban mistakes.

6.3 Future Research

We need to start thinking about not just future cities, but also how these cities are being designed. The combination of genetic algorithms to search through space along with machine learning to evaluate options very quickly, is going to be very powerful and we are already starting to see its potentials. It is exactly what Architect Christopher Alexander envisioned, a technology that allows us to combine the wants and sentiments of a wide range of individuals, not just architects, it has the potential to completely revolutionize development. How might generative design assist cities and development teams with the difficult challenge of assessing all of these conflicting demands and deciding which strategy to pursue? designers, planners, and developers that collaborate with communities to improve places have superpowers thanks to the use of collaborative design technologies. The future development of such tools can add the community comments as a design constraint, and the design will be held responsible for the requirements of the community. If that is possible, we can assess the effectiveness of municipal initiatives by how effectively they satisfy people's needs or improve their quality of life. If we utilize the generative design tools for the development of cities properly, then before the project becomes a reality, the community will have a better understanding of what it means to them and how it will function for them, and this will revolutionize the way we plan not only buildings and neighborhoods, but cities as well. Generative design may assist us in creating better, more human-cantered designs and communities, allowing our cities to emerge from the shadows and into a brighter future. Many designers are rethinking their design processes and using generative tools that autonomously take their ideas in multiple ways, giving them more possibilities to study and explore. When using an iterative design approach, these strategies can assist the designer in balancing more thorough difficulties such as building performance, passive design, carbon neutrality, and the wellness and comfort of the inhabitants. Having the capacity to include additional data into the process aids us in creating better cities that meet all of these requirements at the same time.

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REFERENCES

1. A. M. Turing (1950) Computing Machinery and Intelligence. Mind 49: 433-460.
2. A.E. Eiben & J.E. Smith - Introduction to Evolutionary Computing (2nd edition) (2015)
3. Achim Menges & Sean Ahlquist, ed. - Computational Design Thinking (2011)
4. Alexander, C. (1979). The timeless way of building. New York: Oxford University Press.
5. Alexander, C., Ishikawa, S., & Silverstein, M. (1977). A pattern language: Towns, buildings, construction. New York: Oxford University Press.
6. Alexander, C., Neis, H., Anninou, A., & King, I. (1987). A new theory of urban design. New York: Oxford University Press.
7. Alshehri, A., & Almana, L. (2022). Khobar City Plan and the New Public Space in Saudi Arabia. *The Journal of Public Space*, *6*(1). https://doi.org/10.3390/urbansci2030086
8. Althaqafi, T. A. A., Foster, S., & Rahim, M. (2018). Public value creation using social media applications for the local government context: a pilot case study. Australasian Conference on Information Systems 2018. https://aisel.aisnet.org/ecis2018_rip/22/
9. ArcGIS Urban. (n.d.). Home [YouTube Channel]. YouTube. Retrieved May, 2022 https://www.youtube.com/channel/UCdaz4S6Aas0swo4aGsbokow/featured
10. Arnstein, S. (1969). A Ladder of Citizen Participation. Journal of the American Institute of Planners. https://doi.org/10.1080/01944366908977225
11. Benoit B. Mandelbrot - The Fractal Geometry of Nature (1977)
12. Bouregh, A. (2022). Analysis of the Perception of Professionals in Municipalities of Dammam Metropolitan Area Towards Introducing E-Participation in Saudi Urban Planning https://doi.org/10.4018/IJEPR.297516
13. Cohen-Blankshtain, G. & Gofen, A. (2021). Serial Participation in Urban Planning: The Troublemakers as City Makers? Journal of the American Planning Association https://doi.org/10.1080/01944363.2021.1947872
14. Danil Nagy - AI in space planning, Chapter in Companion for AI in Architecture (Routledge, 2017) https://drive.google.com/file/d/1qGE9A-9XgDdxCDvG3o-IMCtEycmUvrA4/view
15. Danil Nagy, Dale Zhao, David Benjamin - Nature-Based Hybrid Computational Geometry System for Optimizing Component Structure, Design Modelling Symposium (2017)
16. Danil Nagy, et al. - Project Discover: An application of generative design for architectural space planning, SimAUD (2017) https://damassets.autodesk.net/content/dam/autodesk/research/publications-assets/pdf/project-discover-an-application.pdf
17. Danil Nagy, Lorenzo Villaggi - Generative Urban Design: Integrating Financial and Energy Goals for Automated Neighborhood Layout, (2018) https://damassets.autodesk.net/content/dam/autodesk/www/autodesk-reasearch/pdf/publications/Generative-Urban-Design-2018.pdf
18. Danil Nagy, Lorenzo Villaggi, Dale Zhao, David Benjamin. - Beyond Heuristics, ACADIA (2017) https://drive.google.com/file/d/1a84m3fWjzDzfEHhxYUAQurXblIX7bqOk/view

19. Danil Nagy, Lorenzo Villaggi, Jim Stoddart, David Benjamin - The Buzz Metric: A Graph based Method for Quantifying Productive Congestion in Generative Space Planning for Architecture, Technology | Architecture + Design (Taylor & Francis, 2017) https://drive.google.com/file/d/1s0qEqDFsm6nmisfpLyjmlIFrZU1s51bf/view
20. Deutsch, R. (2015). Data-driven design and construction: 25 Strategies for capturing, analyzing and applying building data. John Wiley & Sons, Inc.
21. ESRI's ArcGIS Urban Website. Accessed May 2022. https://www.esri.com/en-us/arcgis/products/arcgis-urban/overview
22. Fabusuyi, T. & Johnson, M. (2021). Enhancing the quality and social impacts of urban planning through community-engaged operations research. Urban Analytics and City Science Journal. https://doi.org/10.1177/23998083211054851
23. Fischer, T., & Herr, C. (2001). Teaching Generative Design. *International Conference on Generative Art.* http://generativeart.com/on/cic/ga2001_PDF/fischer.pdf
24. Future Saudi Cities. (2017). State of Women and Youth in Saudi Cities. UN Habitat and Ministry of Municipalities and Rural Affairs. https://unhabitat.org/sites/default/files/documents/2019-05/state_of_women_and_youth_in_saudi_cities.pdf
25. Jacobs, J. (1961). The death and life of great American cities. Random House: New York.
26. Jacobs, J. (1961). *The Death and Life of Great American Cities*. Random House, New York. https://doi.org/10.22296/2317-1529.2019v21n1p13
27. Kapoor, A. & Singh, D. (2021). Technological solutions to encourage civic engagement in urban planning: experts' perspectives. Journal of Community 20 Positive Practice. https://www.ceeol.com/search/article-detail?id=1007511
28. Kumar, H., et al. (2020). Moving towards smart cities: Solutions that lead to the Smart City Transformation Framework. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2018.04.024
29. Kumar, P. (2015). Smart Neighborhood to Enhance Social Sustainability and Inclusion Planning in Smart Cities. Sustainable Built Environment Conference.
30. Leitão, A., Santos, L., & Lopes, J. (2012). Programming languages for generative design: A comparative study. International Journal of Architectural Computing, 10(1), 139-162.
31. McKinsey Global Institute. (2017) Reinventing Construction: A route to higher productivity. Executive Summary. https://www.mckinsey.com/~/media/mckinsey/business%20functions/operations/our%20insights/reinventing%20construction%20through%20a%20productivity%20revolution/mgi-reinventing-construction-executive-summary.pdf
32. Mukherjee, F. (2015). Public Participatory GIS. Geography Compass. https://doi.org/10.1111/gec3.12223
33. Nabatchi, T. and Leighninger, M. (2015). Public Participation for 21st Century Democracy. Wiley.
34. Nathanian, J., Aleksandrowicz, O., & Auer, T. (2019). A parametric approach to optimizing urban form, energy balance and environmental quality: The case of Mediterranean districts. *Applied Energy, 254*(1). https://doi.org/10.1016/j.apenergy.2019.113637
35. National Association of City Transportation Officials. (2016). *Global street design guide: Global designing cities initiative*. Island Press.
36. Nohemi, R., Farag, A., & Badawi, S. (2019). Smart city vision and practices across the Kingdom of Saudi Arabia—a review. *Smart Cities: Issues and*

Challenges Mapping Political, Social and Economic Risks and Threats 309-332. https://doi.org/10.1016/B978-0-12-816639-0.00017-X
37. Oliveira, S., Gathing, B., & Marco, E. (2020). *Energy modeling in Architecture: A practice guide*. RIBA Publishing.
38. Park, J. & Nam, K. (2021). A Study on the Level of Citizen Participation in Smart City Project. Journal of the Korean Association of Geographic Information Studies. https://doi.org/10.11108/kagis.2021.24.2.012
39. Rauber, A., & Krafta, R. (2018). Alexander's Theories Applied to Urban Design. *Urban Science, 2(*3). https://doi.org/10.3390/urbansci2030086
40. Reichborn-Kjennerud, K.et al. (2021). Exploring the relationship between trust and participatory processes: Participation in urban development in Oslo, Madrid and Melbourne. Nordic Journal of Urban Studies. https://doi.org/10.18261/issn.2703-8866-2021-02-01
41. Reichental, J. (2020). Smart Cities for dummies. John Wiley & Sons, Inc.
42. Reichental, J. (2020). *Smart Cities for Dummies*. John Wiley & Sons, Inc.
43. Reuter, T. (2020). Smart city visions and human rights: Do they go together? *Carr Center For Human Rights Policy: Understanding the impact of technology on urban life*, (6). https://carrcenter.hks.harvard.edu/files/cchr/files/CCDP_006.pdf
44. Saudi Quality of Lift Program 2020 – Document
45. Saudi Vision 2030 – Document
46. Schneider, J., & Kirkpatrick, S. (2006). Stochastic optimization. Springer Science & Business Media.
47. Schreiner, T. et al. (2021). Co-production in public management: a case study towards a smart city. International Journal of Knowledge-Based Development. https://doi/10.1504/IJKBD.2021.119046
48. Shiffman, D. (2012). The Nature of Code, Chapter 9: The Evolution of Code. https://natureofcode.com/book/chapter-9-the-evolution-of-code/
49. Sim, D. (2019). *Soft city: Building density for everyday life*. Island Press.
50. Soward, E., & Li, J. (2021). ArcGIS Urban: an application for plan assessment. *Computational Urban Science*. https://doi.org/10.1007/s43762-021-00016-9
51. Spall, J. (2003). Introduction to stochastic search and optimization. John Wiley & Sons, Inc.
52. Speck, J. (2013). Walkable city: How downtown can save America, one step at a time. North Point Press.
53. Stasiuk, D. (2018). Design Modeling Terminology. Proving Ground Website. https://provingground.io/2018/06/13/design-modeling-terminology/
54. Stuart Russell & Peter Norvig - Artificial Intelligence, A Modern Approach (2010)
55. Tang, K. & Waters, N. (2005). The Internet, GIS and Public Participation in Transportation Planning. Progress in Planning. https://doi.org/10.1016/j.progress.2005.03.004
56. Terzidis, K., (2015). *Permutation design: Buildings, texts, and contexts*. Routledge.
57. UN-Habitat. (2019). Country Profile Saudi Arabia English. https://unhabitat.org/sites/default/files/download-manager-files/Country%20Profile%20Saudi%20Arabia%20English.pdf
58. Veeckman, C. et al. (2021). *Co-creation and Smart Cities: Looking Beyond Technology*. Emerald Publishing Limited. https://doi.org/10.1108/9781800436022
59. Wang, X., Song, Y., & Tang, P. (2020). Generative urban design using shape grammar and block morphological analysis. Frontiers of Architectural Research, 9(4), 914-924.

60. Wilson, L. (2021). The Future of Generative Design. Kohn Pedersen Fox (KPF). https://vimeo.com/522736119

61. Yang, X. (2008). Nature-inspired metaheuristic algorithms (2nd edition). Luniver Press.

62. Zhang, J., et al. (2019). Impact of urban block typology on building solar potential and energy use efficiency in tropical high-density city. *Applied Energy*, *240*(7). https://doi.org/10.1016/j.apenergy.2019.02.033

63. Zhongming, S., et al. (2021). A parametric method using vernacular urban block typologies for investigating interactions between solar energy use and urban design. *Renewable Energy*, *165*(1), 823-841. https://doi.org/10.1016/j.renene.2020.10.067