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DOCTORAL THESIS

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Multi-objective Optimization for Smart City Concepts: Smart Floating Cities (SFC)

DOCTORAL THESIS

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Declaration:

I declare that I worked on this dissertation independently, with the use of cited literature and other sources.

In Hradec Králové 2021 Ayca Kirimtat, M.Sc.

Abstract

Previous to the emersion of two premises “smart city” and “floating cities”, the population of manlike has been enhanced and land shortage has started to be realized by the humankind in the world. Consequently, the conception of intelligent city has been lengthened to the scholar epoch as an original outcome by investigators. Afterwards, the "floating city" conception has been adopted to the literature by a small number of researchers so as to make preparation for fighting with ascending sea levels. On the contrary, constructing an intelligent city is identified as a complicated layout planning amongst scientists, and designers, therefore multi-objective evolutionary optimization could be utilized to figure out this complex design problem by enhancing residents’ requirements. As a result of these statements, the outcomes of various evolutionary algorithms such as Self-adaptive Differential Evolution (jDE), Self-adaptive Continuous Genetic Algorithm with Differential Evolution (JcGA-DE), a nondominated sorting genetic algorithm (NSGAII), and a harmony search (MOHS) algorithm are compared by optimizing opposed objectives in three divergent case studies. In the preliminary case study, the objective functions namely as “visual comfort” and “accessibility” between the functions in the problem of smart floating city, are trying to be optimized. In the following and second design problem, the travelling distances are trying to be minimized while the cost efficiency is being maximized under the sea level. In the last case study, the maximization of natural light and the minimization of total energy consumption are targeted within the smart building. As a continuation of the dissertation, the consequences of the design problems through the Pareto front graphs of different algorithms are associated and discoursed.

The List of Abbreviations

Abbreviation	Explanation
IoT	Internet of Things
jDE	Self-adaptive Differential Evolution
JcGA-DE	Self-adaptive Continuous Genetic Algorithm
NSGAII	Non-dominated Sorting Genetic Algorithm II
MOHS	Multi-objective Harmony Search
CO2	Carbon-dioxide
IS	Information Systems
IoV	Internet of Vehicles
HEMT	Hybrid Emergency Message Transmission
WTC	Wise Traffic Controller
PCSR	Power Controlled and Stability-based Routing
WHO	World Health Organization
ICT	Information and Communication Technologies
IVR	Interactive Voice Response
STE	Smart Tourism Ecosystem
NIST	National Institute of Standards and Technology
QoS	Quality of Service
WoT	Web of Things
DE	Differential Evolution
TSP	Travelling Salesman Problem
HS	Hamony Search
HMCR	Harmony Memory Consideration Rate
PAR	Pitch Adjusting Rate
BW	Distance Bandwidth
UDI	Useful Daylight Illuminance
TEC	Total Energy Consumption

Contents

1. Introduction

The dimensions of cities are constantly growing as denoted in the worldwide forecast reports (Gavalas et al., 2017); consequently, every single day life in urban areas will furthermore be thought-provoking due to restricted resources and services that is medicine, education, environment, and transportation. To withhold the conservation of such services in urbanized regions, original methodologies for felicitous database management should be focused. Smart city as a term is reproduced as an implementation of mobile computing systems by means of functional data managing amongst each part and layer of the district itself (Gavalas et al., 2017). Additionally, cities are further concentrated on the attempts on being more intelligent with the aim of managing data networks like IoT. Such data management units supply refinements in various operation and establishment, which are traffic operation, environmental management, quality of life, and city infrastructure (Ismagilova et al., 2019).

Citizens are becoming more aware of the Internet of Things (IoT), which is a growing network of digital sensors, smart gadgets, and smart home appliances, and prompt attention to any of these technologies may enrich people's quality of life. For instance, in the near future, long-lasting batteries, which are now being developed, will be capable of a lot of work and will be able to charge themselves using daylight, temperature, or motion (Gavalas et al., 2017). This is a perfect illustration of the solutions, which are now being developed for smart cities. Furthermore, each city's smart city goals and major implementations are unique, and these smart gadgets and systems will continue to be employed in the future.

Given the growing population in metropolitan areas, adequate services and environmental demands are difficult to provide; as a result, IoT technologies are considered as a promising alternative for establishing a functioning smart city (Jin et al., 2014). Despite the fact that designing an IoT architecture is a difficult undertaking, this information management technology has indeed been widely used in smart cities mostly in studies by researchers. In this platform, a wide range of gadgets, network layer solutions, and applications must be used (Zanella et al., 2014). Furthermore, those solutions ought to be adaptable to a variety of intelligent locations (Venkatesh et al., 2018); floating cities, which are very common and range from cities and islands that float on water to ones that float in the atmosphere of a planet, seem like one of those habitats, and smart cities could emerge as some kind of smart environment on the planet.

Latest advances within IoT technology shall encourage academics as well as professionals to innovate novel areas of application and IoT applications (Mohammadi et al., 2018), and so these modern digital IoT systems ought to be able to fulfill the requirements of residents all over the planet. Basic societies must also be considered while transferring and gathering information inside IoT initiatives to support consciousness of smart city ideas throughout the global. As a result, the system might have actuation, connectivity, processing, as well as detecting capabilities (Li et al., 2018). Monitoring IoT devices, as well as gathering, archiving, and sharing available sensor data, are essential aims for smart city research and development (Pflanzner et al., 2018). There are several papers in the recent literature addressing various smart city core issues, such as this one on surveillance for smart cities (Montori et al., 2018) and some other fascinating research on people's standard of living in a smart city, which concentrates on four major urban concepts: meteorology, ecosystem, public transportation, and pedestrian movements (Santos et al., 2018). A further significant work concerning smart cities focused on data collection and quality assessment in a semantic Web context (Kolozali et al., 2019), (An et al., 2019).

Even though a smart city is an effective concept for metropolitan areas, other living places must be investigated, and the notion of a smart city must be transported to such alternative living locations. Throughout ages, urban planners, architects, as well as academics have indeed been looking for alternate living places. As a result of increasing sea levels, environmental catastrophes, and destructive human activities, floating communities or settlements have been recognized as a new opportunity for people looking for alternative homes. Such alternative ecosystems, i.e., floating cities, have numerous potential benefits, including offering an environmentally pleasant environment, easy and quick building on the sea level, readily removable and extended construction units, tectonic impact resistance, and cost-effective options. Furthermore, smart city concepts and approaches might be viewed as part of the notion of floating communities or urban areas. As a result of the findings, I propose a novel method entitled "Smart Floating Cities (SFC)," which combines smart city concepts also with creation of floating cities. Because smart city technologies have been developed as new solutions to the world's finite environmental resources and human needs, they must be linked with the notion of floating cities, which is becoming required as sea levels rise. Furthermore, because increasing sea levels are a very devastating natural catastrophe all over the planet due to global warming, the idea of "Smart Floating Cities (SFC)" must be regarded as a critical safeguard against rising sea levels as well as restricted ecosystem services.

The aims are discussed one by one in the next section of this dissertation. Section 3 explains how the suggested framework for the entire research is created. The state of the art is described as well as explored in Section 4. Some smart city concepts are examined under various categories. Section 5 discusses the problem statement for the future smart floating city design issue, which covers design parameters, fitness functions, and constraints. Four multi-objective evolutionary algorithms jDE, JcGA-DE, NSGAII, and MOHS are discussed individually in Section 6 since they are all applied to three separate optimization problems. The outcomes of three separate case studies are given and contrasted in Section 7. In Section 8, the accomplishment of the dissertation's aims, involving study findings and future expectations, is described. Closing thoughts are presented in the final section.

2. Goals of the Dissertation

The research objective and sub-goals are summarized in the following points:

- The main goal of this PHD dissertation is to create a computational theoretical model for smart floating cities by incorporating multi-performance criterion into the design process.
- The first sub-goal of this dissertation is to propose a new concept namely as Smart Floating Cities by combining two popular concepts smart city and floating city.
- The second sub-goal of this dissertation is to develop a smart floating city design in three different case studies utilizing optimization techniques, simulation approaches and computation tasks.

I additionally propose current advancements in prior research as well as the possibility of using previous approaches in future research on other smart city notions. By identifying many important smart city subjects from the Web of Science, the current literature presents numerous researches with varied approaches. Several smart city core topics are studied in this dissertation to comprehend the primary links between them and application examples are provided. I do use the terms "smart city" and "concept" to do comprehensive investigation in the Web of Science.

3. Design of the Proposed Framework

Floating cities are creative and potential urbanized regions for addressing urban and settlement design issues. This design effort, on the other hand, necessitates several concerns as well as technological obstacles. To deal with the intricacy of floating city design, computational tools and methodologies might be useful. Employing computational intelligence approaches, this dissertation explores the construction of a sustainable floating city. In this regard, I explore a design problem for placing every neighborhood function inside a floating area in each cluster with a given density. Moreover, multi-objective evolutionary algorithms are introduced with the aim of building a sustainable floating neighborhood.

Engineering, logistics, finance, and other science areas might all benefit from multi-objective optimization. Optimal selections should be made using more than one objective function and certain restrictions in all of these cases. Problems in computer science are divided into two categories: optimization problems and decision problems. Minimizing and maximizing objective functions are used to try to find the shortest path connecting two vertices of a graph in optimization problems. We try to figure out if there is an answer or if the answer is Yes or No in decision problems. In terms of time complexity, computer science problems are divided into two categories: deterministic polynomial time (P) and non-deterministic polynomial time (N) (NP). Matrix Chain Multiplication, Single Source Shortest Path, All Pair Shortest Path, Minimum Spanning Tree, and other deterministic polynomial time problems, for example, fall to this category because the algorithm is defined. Traveling salesman, optimum graph coloring, Hamiltonian cycles, finding the longest route in a graph, and satisfying a Boolean formula, on the other hand, are all non-deterministic polynomial time problems with unknown condition and algorithms.

In engineering and manufacturing, multi-objective optimization is frequently difficult to solve, demanding the use of complex approaches. When the size and complexity of geometries increase, developing something original has larger demands. As a result of these factors, identifying potential design solutions among all possibilities at the early stages of the design process is extremely challenging. One of the finest examples of difficult engineering challenges is smart city designs. Furthermore, the design of smart cities is typically a multi-objective, high-dimensional optimization issue.

Genetic Algorithms (GA) on the other hand, are search heuristics focused on natural selection and evolution in nature (*Genetic Algorithms and Machine Learning*, 1988). Individuals with D-dimensional decision variables are encoded into chromosomes in GAs to create an initial population, which will be developed across generations. For each generation, two individuals from the population are chosen and mated. Eventually, two individuals are crossed to create new alternatives known as offspring or child. To get away from local minima, some individuals have been mutated. With the aim of selecting new individuals for the following generation, the offspring population is eventually introduced to the parent population. The main scheme of the genetic algorithm is shown in Pseudo Code 1.

Pseudo Code 1. The main scheme of the GA.

$Establish\ initial\ population\ P^t\ at\ generation\ t$

$Evaluate\ individuals\ in\ P^t$

$While\ (not\ termination) do$

{

$Select\ two\ individuals\ from\ P^t$

$Crossover\ individuals\ to\ produce\ offspring\ Q^t$

$Mutate\ some\ individuals\ in\ Q^t$

$Add\ offspring\ Q^t\ to\ individuals\ in\ P^t$

$Evaluate\ (P^t + Q^t) individuals\ in\ P^t$

$Select\ P^t\ individuals\ from\ (P^t + Q^t)$

}

$End\ While$

$End\ Algorithm$

A crossover and mutation operators are required for real-coded GA. To create offspring Q_i^t, I use a basic binomial crossover operator. To put it another way, two individuals, X_a and X_b, were selected from the parent population. Subsequently, with a given crossover probability CR_i^t, each dimension of the offspring is taken from either the first or second person. To create offspring Q_i, Pseudo Code 2 provides an overview of the crossover operator, and also an implementation in Table 1.

Pseudo Code 2. Crossover operator.

$for\ j = 1\ to\ D$

$if\ r_j < CR_i\ then$

$$Q_i^{j,t+1} = X_a^{j,t}$$

$else$

$$Q_i^{j,t+1} = X_b^{j,t}$$

$endfor$

Table 1 Binomial crossover and mutation operator (by author).

j	1	2	3	4	5
CR_i	0.70	0.70	0.70	0.70	0.70
r_j	0.80	0.25	0.92	0.67	0.11
$x_a^{j,t}$	0.15	0.70	0.35	0.45	0.95
$x_b^{j,t}$	0.65	0.75	0.10	0.25	0.05
$Q_i^{j,t+1}$	0.65	0.70	0.10	0.45	0.95
r_j	0.80	0.01	0.18	0.75	0.15
MR_i	0.02	0.02	0.02	0.02	0.02
$Q_i^{j,t+1}$	0.65	0.32	0.10	0.45	0.95

In terms of the mutation operator, as seen in Table 1, certain dimensions of offspring $Q_i^{j,t+1}$ can be altered or disturbed with a low mutation probability.

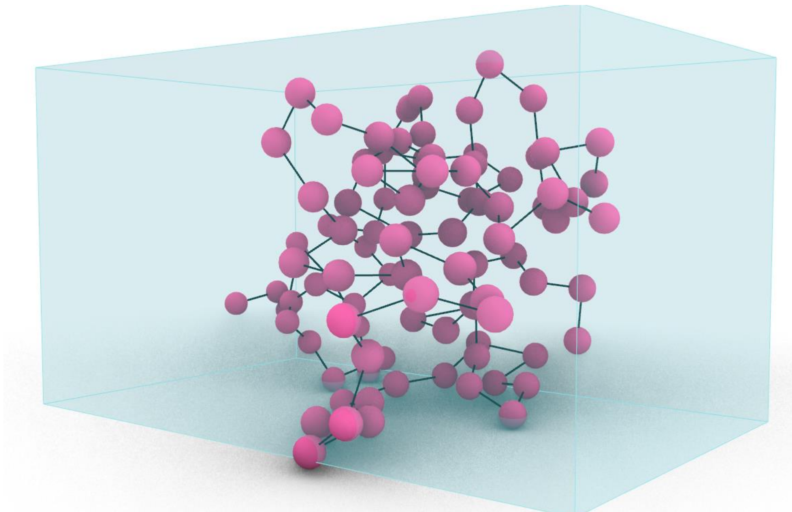


Figure 1 The graphical representation of the parametric model for the objective functions "platform cost" with "traveling distance" (by author).

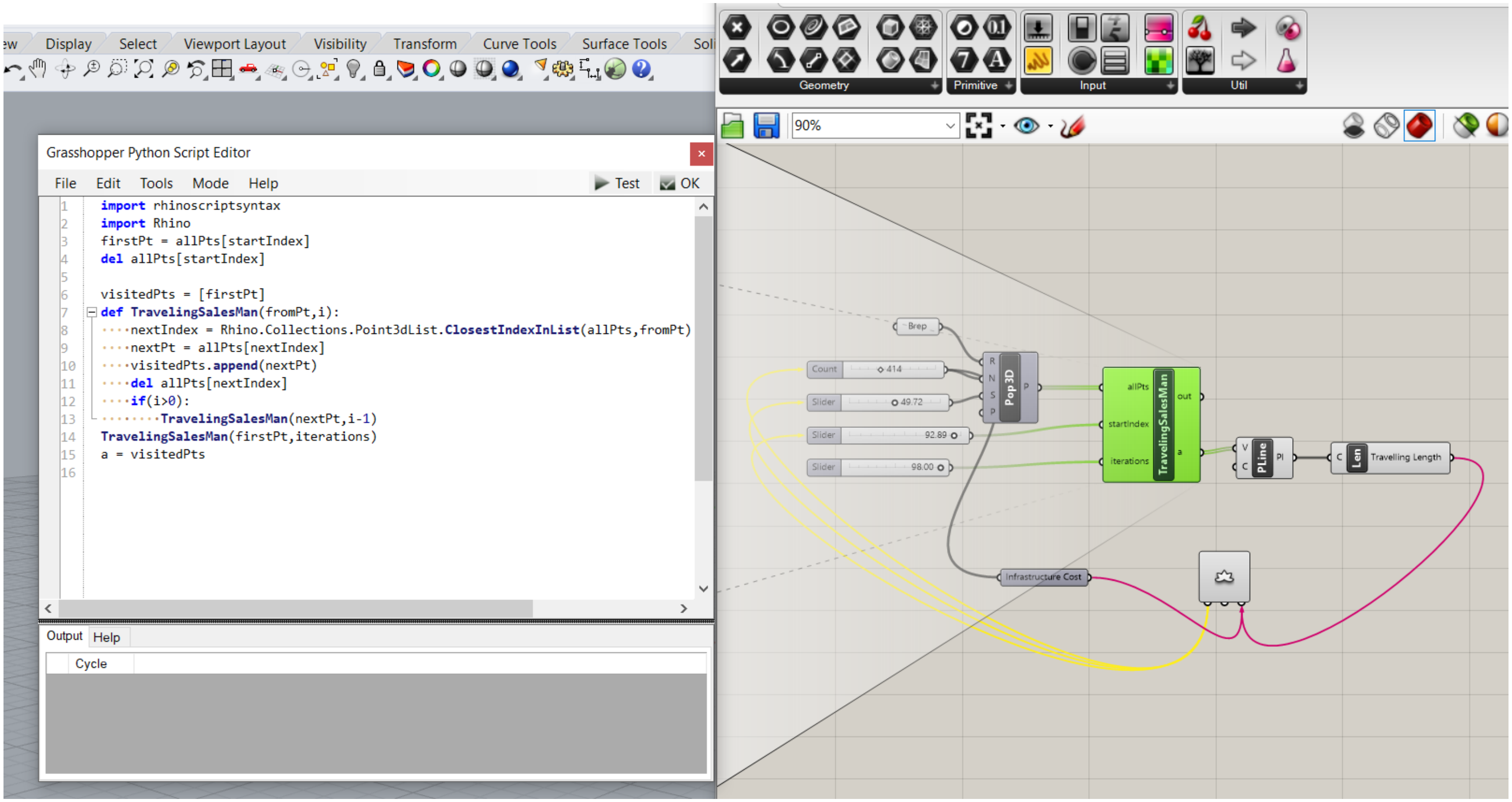


Figure 2 The code for "traveling distance" (by author).

Objective Space | Preferences | Chromosome data | Log | About Lotus

Slider	Slider		Travelling Length	Infrastructure Cost	Constraint Violation	Pareto Rank	Crowding Distance	Relaxation Angle
47.1531778107803	100	412.903437430967	187.720173673637	413	0	0	4.24418024446499	0
43.7512825315126	55.1361742173956	109.239911115211	338.22398643655	109	0	0	4.30342597170926	0
44.0010749963117	71.8225840347924	319.421347478065	207.340043037727	319	0	0	4.73162832464725	0
61.6781988573625	40.377443204344	595.621397994765	165.402617606282	596	0	0	4.76188574334525	0
35.2306904666647	100	141.48558348924	293.641834812735	141	0	0	4.78555636074401	0
0	1.01646233536105	599.005060169848	163.060880875358	599	0	0	4.84859879091179	0
75.8182885691779	100	107.680994835485	338.488048075414	108	0	0	4.8672112679331	0
99	0	329.195279697331	206.80871740804	329	0	0	4.92602707703121	0
61.2351723273365	72.747480414552	826.196016380255	145.574119904476	826	0	0	5.06667981374422	0
0	88.8963213539692	420.50337123082	186.695301492407	421	0	0	5.0962377561204	0
0	66.488176734414	324.468100602214	206.886498189645	324	0	0	5.26566281484371	0
66.9656002269223	82.2149794826095	253.551924589603	226.96095375859	254	0	0	5.34054797540246	0
12.5941335268362	19.8651369287936	671.91183186631	156.46698392884	672	0	0	5.4600087959805	0
99	72.747480414552	370.485394620496	196.437170996901	370	0	0	5.48070758391954	0
93.5642919449901	97.1196843763439	422.071714709546	186.527698161396	422	0	0	5.56138331506671	0
0	0	821.528804405373	146.701734602582	822	0	0	5.64574883450381	0
35.6440427091321	53.1692665783545	118.804210851339	319.889322427829	119	0	0	5.74019194771992	0
62.1076159158291	0	591.651903497026	165.584652362048	592	0	0	5.88679009661718	0
7.01951797778918	53.1692665783545	138.152173551802	294.17306246416	138	0	0	6.29727508881783	0
49.2832829780927	20.3808259794913	701.180390549926	154.798462876833	701	0	0	6.31258029433639	0
0	92.2133739265973	121.96325286047	314.234362223142	122	0	0	6.33604032379216	0
43.7512825315126	66.7627269554766	260.948613399252	225.825545928739	261	0	0	6.41850958980739	0
8.33278921348547	35.456676083729	185.202428289237	260.052061050061	185	0	0	6.47835167296401	0
59.2429145306362	16.7422471095127	180.187903675033	260.496873533083	180	0	0	6.48874663125866	0
74.1753474414173	38.1999634854495	130.041684452568	304.773430669174	130	0	0	6.63470300532819	0
0	35.2951707933623	127.522976753545	306.505791001027	128	0	0	6.72190555553527	0
16.2531882270021	56.5852605523438	117.763918093494	321.714746118582	118	0	0	6.72556726140994	0
55.2101957182443	74.2869938045214	366.983101891811	198.294716272719	367	0	0	6.77615140400772	0
94.7124169394283	75.6966131861506	125.047072340813	313.217241780245	125	0	0	6.86428561105762	0
0.569171597780468	100	340.18652967186	203.313471169133	340	0	0	6.92137783145871	0
38.5230605128157	56.9728523525283	331.522188341127	205.034444035583	332	0	0	7.2476231194531	0
75.8182885691779	39.0517550297226	343.760620394788	203.191688372665	344	0	0	7.26680377681396	0
16.6712883345719	65.8241875644693	111.097408882853	332.881196131996	111	0	0	7.44176474295082	0
76.1604698315637	74.2869938045214	977.441549183081	138.099253074985	977	0	0	7.9989190017895	0
47.1531778107803	100	412.903437430967	187.720173673637	413	0	0	8.0124360906147	0

Figure 3 The entire parametric model's chromosome data (by author).

The specifics of the parametric model generated in the software Rhino3D Grasshopper are shown in the aforementioned pictures from Figure 1 until Figure 3. Figure 1 depicts the parametric representation of the proposed smart floating city in terms of two competing objective functions. Figure 2 shows the specification of the code for the traveling salesman problem, which is developed in the C# programming language. Figure 3 depicts the chromosome data from the two competing objective functions. The values of the objective function and the violation of constraints are represented by this data. The whole structure for the suggested case studies is depicted in Figure 4.

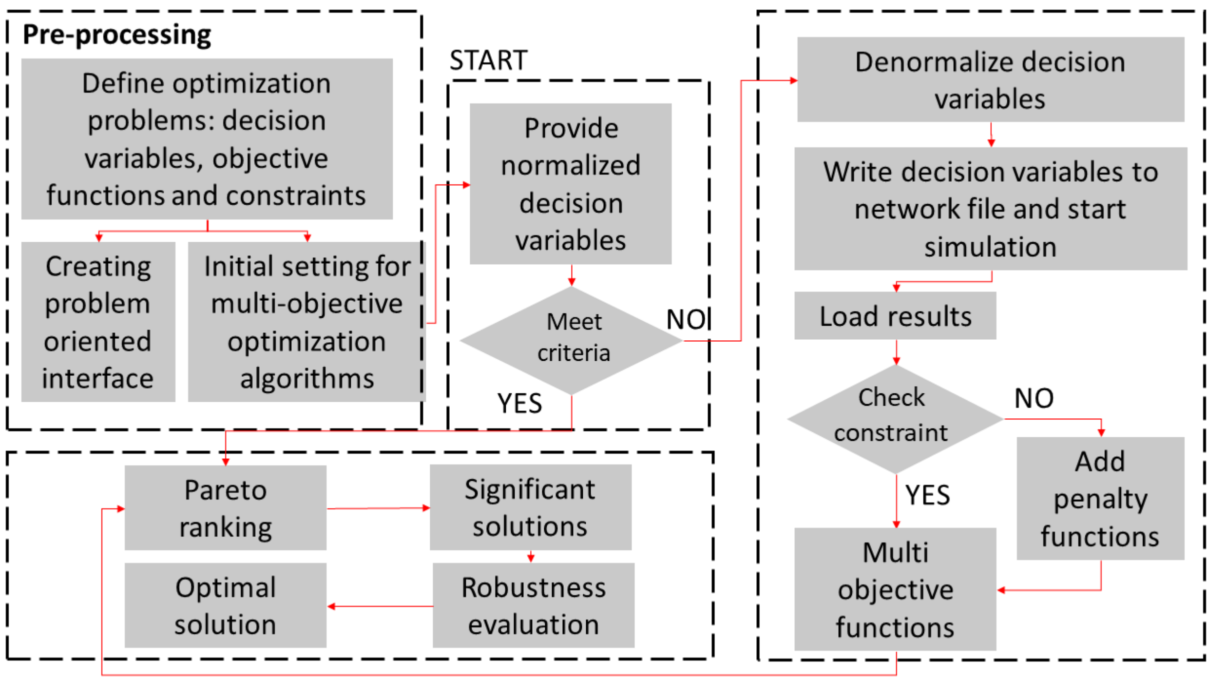


Figure 4 The structure for the entire dissertation that has been proposed (by author).

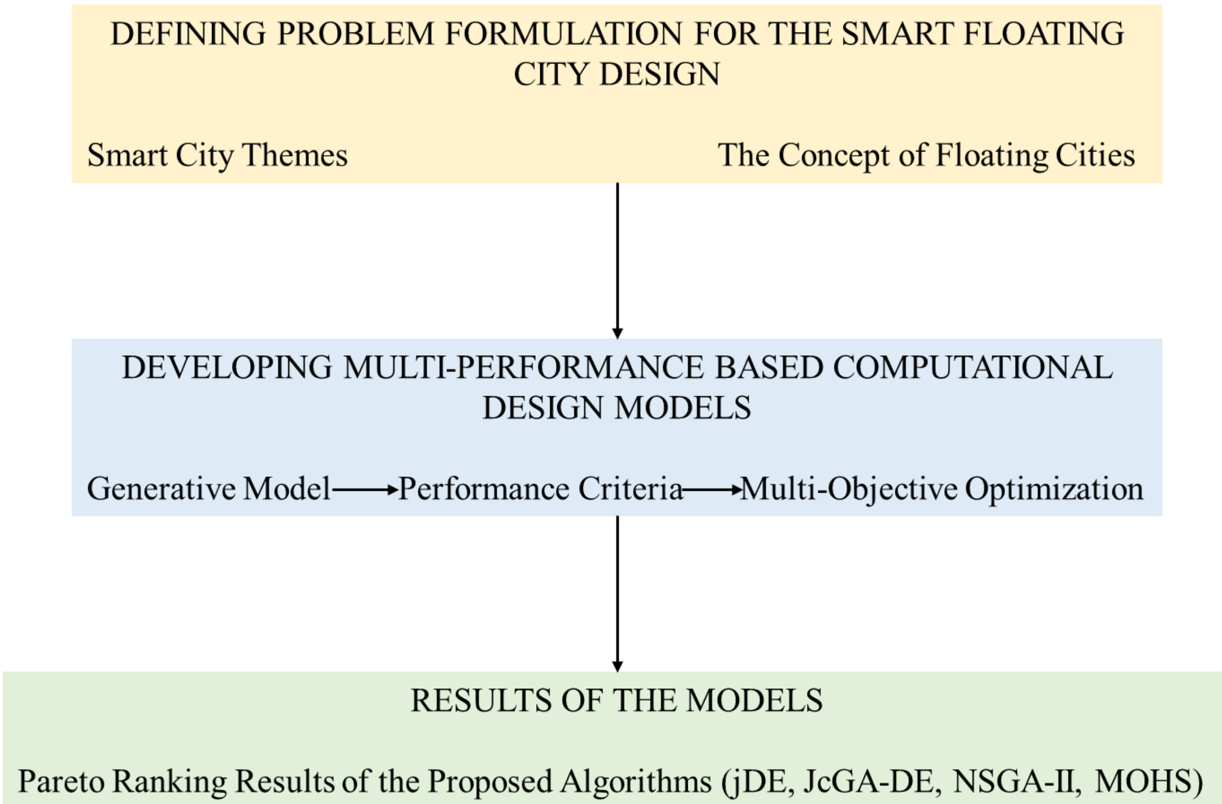


Figure 5 The dissertation's method as a schematic example (by author).

Three key components, as shown in Figure 5, with their captions, are discussed in order to comprehend the Figure 4 workflow: The first section is problem description (pre-processing), in which each case study's problem is specified and created independently, complete with decision variables, objective functions, and constraints. After pre-processing, the performance evaluation phase begins, during which simulation and optimization procedures take place. The last section deals with multi-objective optimization issues and Pareto ranking outcomes. The following subsections provide more thorough explanations of these components.

3.1. Problem Definition (Pre-processing)

The phrase "smart city" has developed as a creative approach for maintaining inefficient metropolitan areas, and it makes use of sustainable and environmental resources. On the contrary, since land shortage has already started, the phrase "floating city" has only been explored for a few years as an alternate dwelling place for mankind throughout the planet. Consequently, numerous design approaches, including digital modeling, simulation, and others, must be integrated into the iterative process of creating a building or a city, and many criteria must be addressed simultaneously. The primary purpose of any design process, on the other hand, is to fulfill each conflicted objective function. Some objectives change in city planning, such as structural safety, climatic comfort inside the complex, and energy efficiency, among others.

It is well understood that developing a computational design model with several objectives to satisfy at the same time is a difficult undertaking. Most of the time, these goals are at opposition with one another due to the building or city program, client priorities, and targets. In addition, there are several design factors, often known as decision variables that can have a significant impact on the entire system design. As a result, designers have exclusive responsibility for constructing living environments for individuals all over the globe.

As a result, as one of the case studies in a "smart floating city" scenario, I present multi-objective optimization methods to achieve the Pareto front options for the cuboid open traveling salesman problem. For example, given n nodes and the distances between each pair of nodes, the TSP in this dissertation seeks to discover the shortest possible tour with the smallest possible traveling distance that begins at the depot (i.e., node 1) and visits each node precisely once without returning to the depot.

3.2. Performance Evaluation

I concentrate on multi-objective optimization of computational benchmark problems in my dissertation by providing better solution approaches, one of which is evolutionary algorithms. Benchmark problems are primarily defined as a collection of standard optimization problems, but they may also refer to a set of data that is computationally challenging to assess and describe. Accordingly, the prediction outcomes might be influenced by the performance of various algorithms. Real-world applications or randomly created issues might be used as benchmarks. In the subject of evolutionary computing, function optimization tests frequently include comparing multiple methods under diverse environmental circumstances.

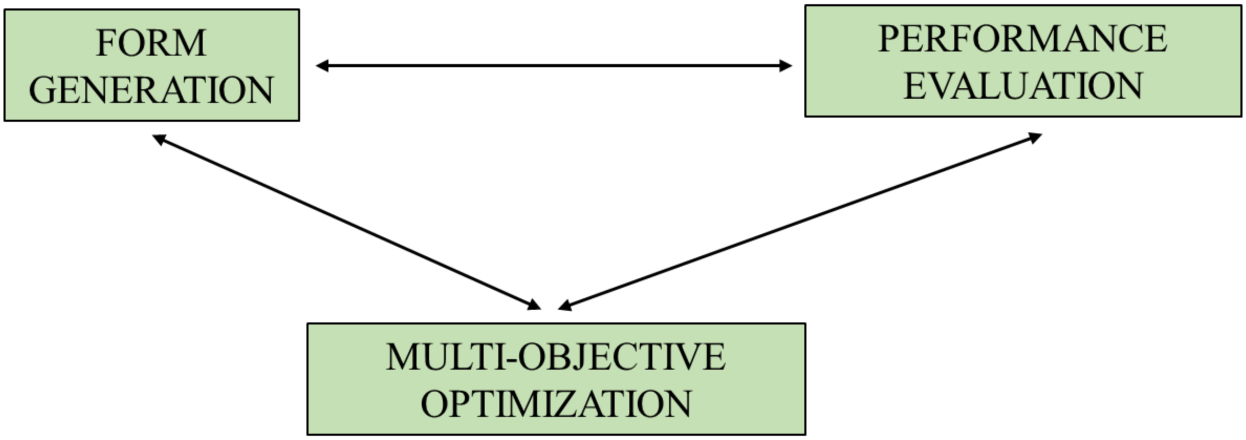


Figure 6 The multi-performance based computational design process (by author).

The shading device developed model throughout this work for a selected case study building is based on "performance driven conceptual design." This approach is characterized by the author (Sariyildiz, 2012) as a loop including phases such as "form generation," "performance evaluation," and "optimization.". Figure 6 depicts this scenario.

3.3. Optimization and Pareto Ranking Results

In one of the case studies, this dissertation tries to identify Pareto front alternatives by reducing the traveling distance and platform cost of infrastructures beneath sea level at the same time. To tackle the challenge, I devise a multi-objective self-adaptive differential evolution (jDE) method, a nondominated sorting genetic algorithm (NSGAII), and a harmony search (MOHS) approach that minimizes the traveling distance while also lowering the platform cost. Each algorithm is compared against the others. In terms of frequently used performance indicators from the literature, the jDE and NSGAII algorithms outperform the MOHS method, according to the computational findings.

Furthermore, the decision-maker must choose certain options from a large number of design alternatives generated by the optimization process, which is not always simple. To discover ideal solutions based on preferences, the decision-maker must also examine many variables such as cost, sustainability, environmental concerns, and so on. In this dissertation, I attempt to solve the challenge of combining competing objective functions in just the same design option. The suggested generative models might be beneficial for aggregating preferences into a single design choice.

4. State of the Art

"A Smart City is the kind that handles such growth by succeeding in many important categories; economics, transportation, ecosystem, citizens, society, and administration." as shown in a United Arab Emirates Government study (*Smart Cities: Regional Perspectives*, 2015). Considering this statement, I conduct a thorough analysis of relevant literature to discover essential concepts of smart city ideologies.

By 2012, many research papers from various journal types have offered distinct meanings of the concept smart city throughout the Web of Science. I conduct a thorough literature review of the relevant papers and compile a list of those published in higher impact journals with Q1 and Q2 rankings in Table 2. The majority of the definitions focused mostly on preferences and features of a smart city.

4.1. Current Definitions of a Smart City

According to the authors (Lazaroiu & Roscia, 2012) one of the most essential aspects of their smart city is sustainable development, because cities use 75 percent of global energy output and generate 80 percent of CO_2 emissions. The approach proposed in this work was designed to improve energy efficiency and a harmonious use of supplies. Utilizing PV-integrated and energy-efficient built environment, as well as smart grid technologies, the authors (Yamagata & Seya, 2013) explored appropriate land use around the city. They claimed that a compact urban city structure lowers the city's residences electricity needs. As in Green and Sustainable Science and Technology field, the authors (Calvillo et al., 2016) characterized their smart city both as environmentally responsible and resource efficient city area. A sustainable community, according to the article's assertions, must maximize resource allocation while still providing a good quality of life. Thus, they utilized simulation modeling to analyze the technological and policy implications of smart solutions.

The authors (Galán-García et al., 2014) suggested a city model with good road network and cost-effective smart traffic lights and signals; they came up with a hybrid model, which included cellular automata and neural network models. Because it concentrated on computer theories within theoretical informatics, this work was published in the Journal of Computational and Applied Mathematics.

Studies on smart city applications in the context of economic growth, social connections, and leadership challenges have been published in business and government publications (Ben Letaifa, 2015), (Sarma & Sunny, 2017), (Yeh, 2017). One research (Yeh, 2017) focused on establishing a paradigm for regional and administrative collaboration. According to the assertions in the study, smart cities must invest in resources by giving wealth and satisfaction, as well as enabling companies. Lastly, intelligent residents must contribute their knowledge and new ideas to the city.

The number of definitions depending on years is shown in Figure 7. From 2012 to 2021, there is a rise of definitions, as illustrated in Figure 7. Furthermore, following the definitions in Table 2, the idea of smart city is moving away from energy-related sustainability concerns and toward the integration of Information Technologies. Nevertheless, as seen in Figure 8, the most referenced journal papers are in publications dealing with energy and sustainability. The most citations are in the Renewable and Sustainable Energy Reviews publication, followed by Applied Energy. With a total of 103367 citations, the Energy journal is in third position.

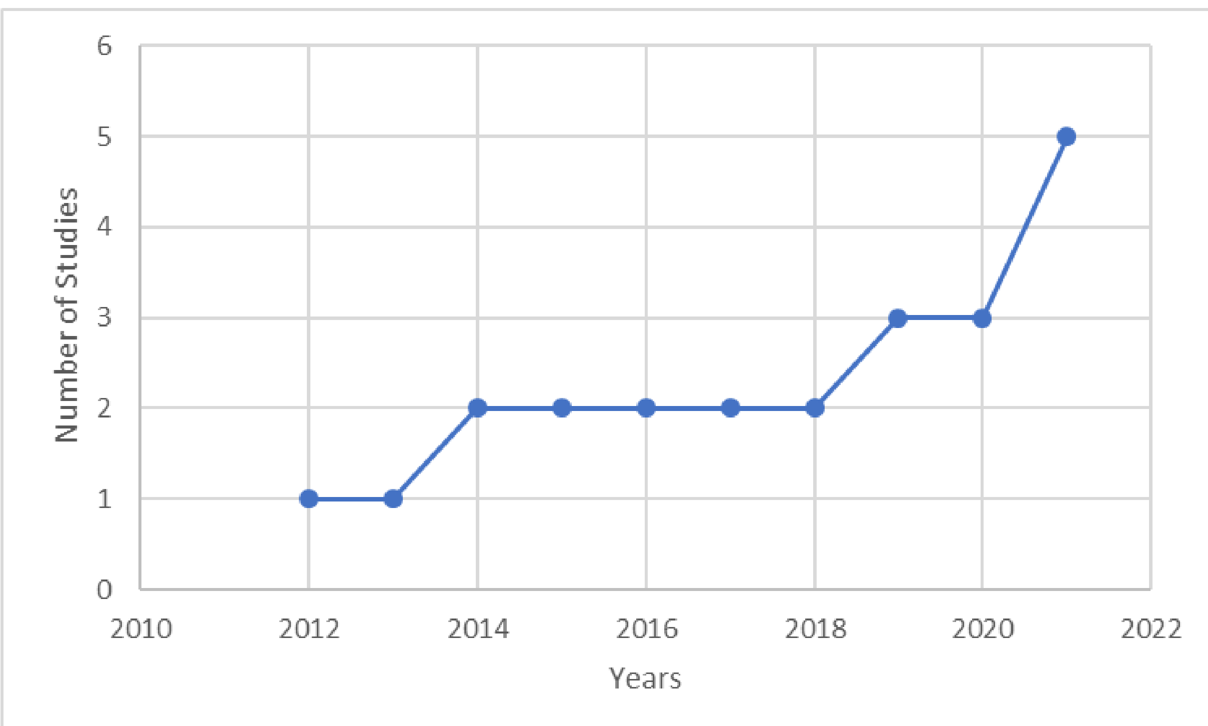


Figure 7 Between 2012 and 2021, the number of smart city definitions in journal publications in Q1 and Q2 (by author).

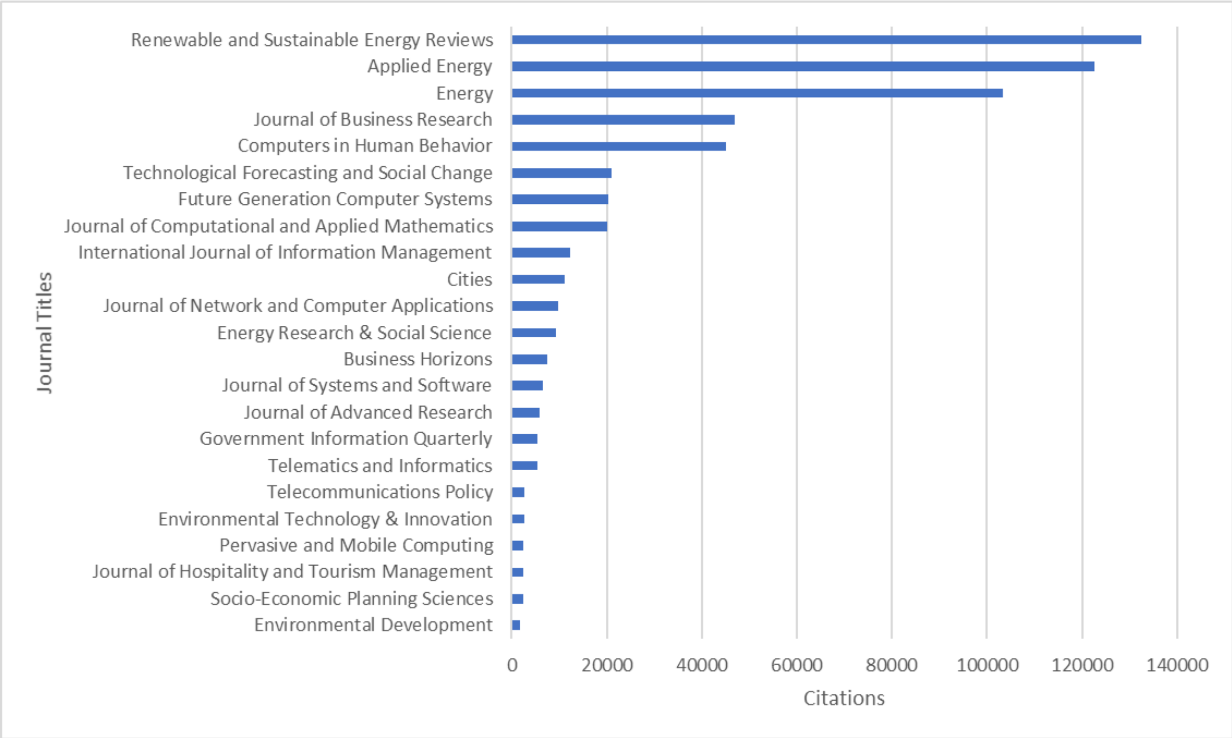


Figure 8 Citation counts for the journals listed in Q1 and Q2 until July 2021 (by author).

Table 2 The WoS's Existing Smart City Interpretations (by author).

Definition	**Year**	**Journal**	**Category (WoS)**	**Journal Rank (WoS)**	**Journal Citation (July 2021)**
"A *smart city* is a city of average technological scale that is linked and ecological, as well as pleasant, beautiful, and protected." (Lazaroiu & Roscia, 2012).	2012	Energy	Thermodynamics/Engineering, Chemical/Energy&Fuels	Q1/na/Q1	103367
"A *smart city* is a concept that integrates suitable land usage (compact city with energy efficient buildings and PVs), mobility (electric vehicles and transit systems), and energy generation (smart grid)." (Yamagata & Seya, 2013).	2013	Applied Energy	Engineering, Chemical/Energy & Fuels	Q1/Q1	122712
"A *smart city* is a concept that has a solid handle on its internal road network." (Galán-García et al., 2014).	2014	Journal of Computational and Applied Mathematics	Mathematics, Applied	Q1	20107

"A *smart city* is a concept that contains smart energy monitors, security gadgets, and smart health and household appliances, among other things, all of which provide unparalleled comforts and better quality of life." (Elmaghraby & Losavio, 2014).	2014	Journal of Advanced Research	Multidisciplinary Sciences	Q1	5927
"A *smart city* is a concept that includes intelligent applications that regulate the whole waste management line derived from remotely sensed measurements, making the essential procedures easier to complete and maximizing performance." (Anagnostopoulos et al., 2015).	2015	Journal of Systems and Software	Computer Science, Software, Graphics, Programming/ Computer Science, Theory & Methods/ Computer Science, Software Engineering	na/Q1/Q2	6579
"In an IT-based city area, a *smart city* is a concept that can combine and coordinate official leadership with internal political involvement." (Ben Letaifa, 2015).	2015	Journal of Business Research	Business	Q1	46935
"A *smart city* is a concept that is designed to cope with or alleviate the difficulties caused by fast urban	2016	Renewable and Sustainable	Energy & Fuels/Green and Sustainable Science and Technology	Q1/Q1	132560

expansion, such as electricity generation, waste management, and transportation, by maximizing performance and resource management.” (Calvillo et al., 2016).		Energy Reviews			
“A *smart city* is a concept that has a network capable of effectively transporting information from various sources to places wherever big data is gathered, processed, and analyzed, as well as conveying responds to the various organizations.” (Hashem et al., 2016).	2016	International Journal of Information Management	Information Science and Library Science	Q1	12245
“A *smart city* is a concept that uses open discourse and technological advances to stimulate social and economic development.” (Sarma & Sunny, 2017).	2017	Business Horizons	Business	Q2	7443
“A *smart city* is a concept that leads to better stability and economic development by motivating and enabling companies to invest their skills and resources in cities, as well as by	2017	Government Information Quarterly	Information Science and Library Science	Q1	5379

delivering more wealth and satisfaction for its residents." (Yeh, 2017).					
"A *smart city* is a concept that supports the automated and efficient administration of urban services and infrastructures, as well as reduced public expenditure and better customer service, by concentrating on issues like energy conservation, sustainable transportation, e-government, social services, and safety." (Palomo-Navarro & Navío-Marco, 2018).	2018	Telecommunications Policy	Communication/ Telecommunications/ Information Science & Library Science	Q2/Q2/Q2	2745
"A *smart city* is a concept that has a suitable governance structure in place to link all factors at work, allow information transfer, and facilitate decision-making in order to optimize their environmental and social performance." (Ruhlandt, 2018).	2018	Cities	Urban Studies	Q1	11076
"A *smart city* is a concept that blends developments in Internet of Things, Big Data, Social Networks, and Cloud	2019	Future Generation	Computer Science, Theory and Methods	Q1	20345

Computing technology with the need for cyber–physical applications in public-interest areas including healthcare, crime prevention, and transportation.” (de M. Del Esposte et al., 2019).		Computer Systems			
“A *smart city* is a concept that incorporates information and communication technologies to improve residents' quality of life, the usage of new advances in technology in order to better utilize available resources, strives for sustainable development in order to meet international commitments, and fosters a culture of entrepreneurship that tends to attract emigrants.” (Curzon et al., 2019).	2019	Pervasive and Mobile Computing	Computer Science, Information Systems/ Telecommunications	Q2/Q2	2540
“A *smart city* is a concept that meets its goals in terms of safety, transportation, adaptability, reliability, and sustainability.” (Elsaeidy et al., 2019).	2019	Journal of Network and Computer Applications	Computer Science, Software, Graphics, Programming/ Computer Science, Interdisciplinary Applications/ Computer	na/Q1/Q1/Q1	9700

			Science, Software Engineering/ Computer Science, Hardware & Architecture		
"*Smart cities* are cities that can make innovative contributions to residents' health care." (Wu et al., 2020)	2020	Socio-Economic Planning Sciences	Management/Economics/ Operations Research & Management Science	Q2/Q1/Q1	2347
"*Smart city* is a city that focuses on smart governance, smart citizen and smart infrastructure." (Prasad & Alizadeh, 2020)	2020	Telematics and Informatics	Information Science & Library Science	Q1	5351
"*Smart cities* are cities that attract more people from the nearby countryside along with an increasing number of tourists." (Eichelberger et al., 2020)	2020	Journal of Hospitality and Tourism Management	Management/ Hospitality, Leisure, Sport & Tourism	Q2/Q2	2467
"*Smart city* is a city that supports local policy objectives." (Clement & Crutzen, 2021)	2021	Technological Forecasting and Social Change	Regional & Urban Planning/Business/Planning & Development	Q1/Q1/na	21116

"*Smart city* is a city that promotes sustainable development practices to minimize the challenges of urbanization in the future." (Razmjoo et al., 2021)	2021	Energy Research & Social Science	Environmental Studies	Q1	9250
"*Smart city* is a city that requires the organic integration of a good ecological environment with people's healthy life." (Z. Chen, 2021)	2021	Environmental Technology & Innovation	Biotechnology & Applied Microbiology/ Environmental Sciences/Engineering, Environmental	Q1/Q1/Q2	2657
"Smart cities are smart service systems according to a socio-technical view that analyzes the impact of technology in the co-creation of economic, social and cultural value." (Kashef et al., 2021)	2021	Computers in Human Behavior	Psychology, Multidisciplinary/ Psychology/ Psychology, Experimental	Q1/na/Q1	45035
"Smart cities are cities that build more efficient and livable urban environments." (Thornbush & Golubchikov, 2021)	2021	Environmental Development	Environmental Sciences	Q2	1702

4.2. Analysis of Smart City Concepts by Themes

The literature describes several essential components that make up a smart city; hence, most of these components, such as smart people, smart economy, smart governance, smart transportation, smart environment, and smart living, are all of concern in this research. To create Figure 9, VOS viewer software is implemented to release the main themes about smart cities. To produce this image, I do a second in-depth literature search in Web of Science using terms like "smart city" and "concept". The network visualization extracts 155 elements (keywords), 2 clusters, and 8034 connections from the 500 publications (224 papers, 228 book chapters, and 58 review articles) throughout the Web of Science. Cluster 1 includes topics such as citizen, economics, government, policy, and sustainability. Cluster 2 contains essential terms such as transportation, healthcare, privacy, and security. Table 3 shows the most often used phrase criteria, such as which items correspond to which cluster numbering and how many linkages and occurrences each item has. Cluster 1 is shown in red, while Cluster 2 is shown in green. The term "citizen" is in Cluster 1 and has 149 relationships with other terms, with a 62-recurrence rate.

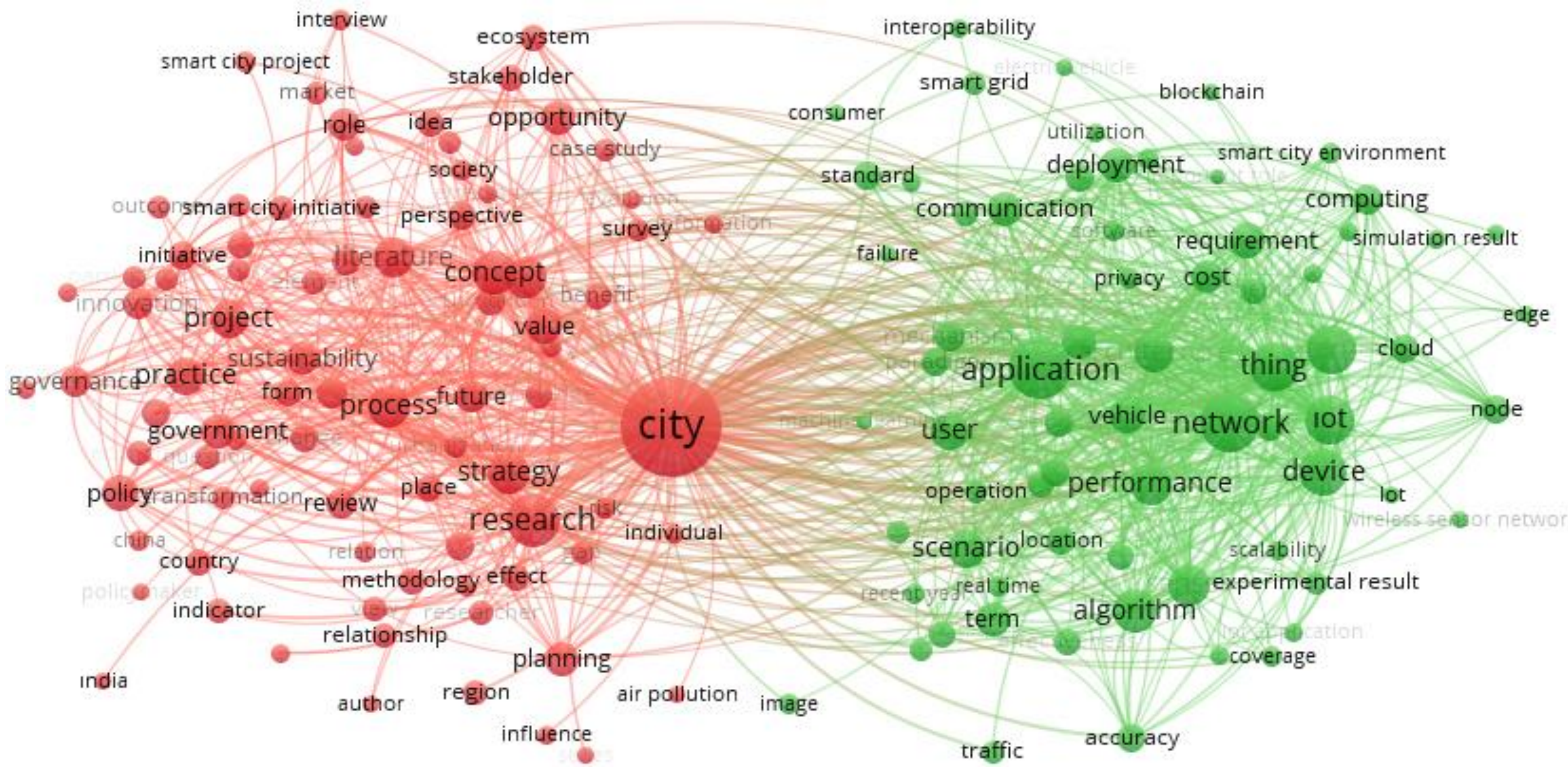


Figure 9 The representation of smart city concepts as a network (by author).

Table 3 VOSviewer's most common keywords within this dissertation (by author).

Item (Keyword)	**Cluster no.**	**Links**	**Occurrences (Existence in the literature)**
Citizen	1	149	62
Economy	1	102	24
Governance	1	110	34
Policy	1	120	46
Sustainability	1	120	37
Transportation	2	120	31
Healthcare	2	71	15
Privacy	2	87	17
Security	2	129	41

The main themes, on the other hand, may alter depending on the needs and goals of the city. More future study should be encouraged to both assess and maximize diverse standards and viewpoints for smart cities as long as technological innovations meet human needs. In the block chain diagram for smart cities, Figure 9 shows the connections between the primary themes and others.

I also provide the key smart city topics reached from the literature through collecting smart city terminologies from the Web of Science including Q1 and Q2 academic journals. Table 2 explains why these particular themes are chosen for this investigation. In the subsections that follow, I define smart people, smart economy, smart governance, smart mobility, smart environment, and smart living one by one.

4.2.1. Smart People

Because people are the primary consumers of smart devices and services, it is crucial to correctly design and build those services (Yeh, 2017), (Belanche-Gracia et al., 2015), (Chatterjee & Kar, 2018), (Chatterjee et al., 2018), (van Zoonen, 2016). The literature discusses important issues about life in smart cities. For instance, the authors (Chatterjee & Kar, 2018) investigated the variables that influence the use of Information Systems in smart cities, depending on the size of information and services. The authors (Belanche-Gracia et al., 2015) addressed security and safety problems in relation to the research of smartcard solutions for public facilities and transports in a separate study. According to (Yeh, 2017), social networking platforms must be taken into account because they educate the public regarding smart city networks and applications by giving relevant information. Each of these elements must be carefully considered and implemented because they affect people's quality of life (An et al., 2019).

People in smart cities must cooperate with one another in order to share fundamental and essential social networking experiences as well as shared environment with many other people. (Sproull & Patterson, 2004), (J. Sun & Poole, 2010). Smart people not only should use services to communicate with one another, but they must provide some data to such services. For instance, (Niforatos et al., 2017) suggested a crowd-sourced weather software, which incorporates automatic measurement results from smart phones with manual input from individuals to analyze data on current and prospective meteorological occurrences. Another author (Mone, 2015) conducted a crowd-sourced cycling route analysis with the goal of enhancing citizen engagement and highlighting potential long-term profitability for bikers. City planners utilized this information to evaluate traffic and develop the city structure by installing racks or enlarging lanes.

Because smart people are already at the core of smart cities, they must be open-minded, responsive to new environmental factors, and innovative. Citizens should take part in each transition in the city since they are the ones who are constructing it, and they must consider what kind of community they desire. Citizens should be informed on the rules and policies that govern how they use the data processing context. Furthermore, social networking sites must educate users about smart city technologies and services that offer data (An et al., 2019).

4.2.2. Smart Economy

Within the concept smart city, a smart economy primarily refers to smart business and mobile commerce (Johnson et al., 2014), (Ludlum, 2013). The authors (Johnson et al., 2014) offered a framework in predictive and deterministic architectural modeling, which is related to a risk-based strategy and the administration of changes in the market inside a firm. Almost all of the practical and commercial benefits of the smart economy, as well as the interaction between both the economic system and residents, have been addressed in current literature studies (An et al., 2019). According to the authors (Keegan et al., 2012), e-commerce platforms may function in smart cities by assisting businesses in increasing customer satisfaction. The study examines a m - shopping solution for prospective consumers that gives information on any goods the consumer is willing to purchase. Therefore, in the light of a smart economy, which takes people' privacy concerns into consideration, harmonizing the link between innovation and customer experience becomes a difficulty (An et al., 2019).

4.2.3. Smart Governance

Municipalities might utilize social media for marketing purposes by encouraging residents to engage and contribute in smart cities (An et al., 2019). According to the study of (Díaz-Díaz & Pérez-González, 2016), engaging in social media is a successful method; nevertheless, the governments must be engaged in the process. Furthermore, knowledge transfer must be provided, and privacy and security concerns must be addressed. Another research (Gascó-Hernandez, 2018) used Barcelona as an example to illustrate how a citizen collaboration may help with the creation, operation, and assessment of smart city initiatives. The authors (Rana et al., 2019) The authors (Rana et al., 2019) concluded that the government is the most significant impediment to developing e-governance solutions to make smart city decision-making visible.

The provision of municipal services, platforms, smart mobile services, and database administration to people is critical to the success of smart city governance (Cledou et al., 2018), (Fietkiewicz et al., 2017), (Guetat & Dakhli, 2016), (Sussman, 2001), (Walravens, 2012). Consequently, smart governments will not only be forward-thinking in their pursuit of technology advancements, but also have smart governmental administration and laws that allow people to participate in the activities (An et al., 2019).

Efficiency, efficacy, openness, and cooperation were presented as criteria to evaluate the smartness of public services in a research by (Nam & Pardo, 2014). In another research by (Gil-Garcia et al., 2016), the various aspects of government were described in the light of smart cities, including assimilation, creativity, knowledge-based decision-making, citizen integrity, sustainability, originality, usefulness, productivity, equality, entrepreneurial spirit, citizen engagement, openness, stability, and technology savvy.

Cloud-based IS services must meet the need for long-term administration of facilities in smart cities (Truong & Dustdar, 2012). IS and related services must be encouraged through interaction between stakeholders and government entities to boost public involvement and engagement; hence, developing partnerships in any setting will raise the effectiveness of smart governance principles. (Viale Pereira et al., 2017).

4.2.4. Smart Mobility

One of the primary challenges, which cities are now experiencing, is managing vehicle capacity levels depending on road expansion, and this topic is explored in scholarly publications about intelligent transportation (Adart et al., 2017), (Dimitrakopoulos & Demestichas, 2010). IoV has made a positive contribution by actively participating in intelligent transport systems. In this respect, there are indeed a range of products aimed at improving road safety performance (J. Chen et al., 2015) . For example, to offer appropriate and flexible network administration, (Zhu et al., 2018) employed a HEMT technology using IoV.

Another research (Adart et al., 2017) focused on traffic control by examining urban transport infrastructure and proposing a solution for vehicles that allows them to arrive on time without encountering traffic jams. By identifying two services, the authors (Calderoni et al., 2014) presented a system that might collect data from various sensing devices. The primary system was mobile traffic management, and the other system was WTC. Regarding the traffic management regulations, these two methods enhanced congestion and urban transport networks.

Another study by (G. Lee et al., 2017) concentrated on traffic monitoring and proposed a unique approach for tracking vehicles in real time. This approach improves monitoring of numerous vehicles at the same time and forecasts of a tracker's probable central region across a series of scenarios. The authors (Zhang et al., 2017) evaluated route stability by introducing the PCSR standard, a route optimization method that improves energy efficiency and network consistency. Another paper (Kumar et al., 2017) investigated the competition of four cities across india, involving Delhi, Kolkata, Mumbai, and Chennai, by using secondary information. The researchers looked at smart city projects and weighed the pros and cons of applying them in various metropolitan areas in order to establish smart cities.

4.2.5. Smart Environment

With the guidance of academics, smart environments have recently become popular, and so these environments are one of the most important aspects of smart cities. (An et al., 2019). A smart environment consists of environmental quality, ecofriendly water spaces, emission monitoring, waste treatment, clean energy, and municipal plant surveillance (Al-Hader et al., 2011), (Anagnostopoulos et al., 2015), (Corbett & Mellouli, 2017), (Castelli et al., 2017), (Niforatos et al., 2017), (Park et al., 2013), and (Zhang et al., 2017). For instance, in the concept of smart cities, (Al-Hader et al., 2011) attempted to tackle the challenge of observing municipal plants. Because tree species may break wires and create power outages, a dynamic laser scanning system was created to detect trees across the area.

According to the researchers (Castelli et al., 2017), air pollution may harm the environment, and cities are presently dealing with this issue. Annually, according to the WHO, people die as a result of environmental pollution. As a result, some study has concentrated on using surveillance devices to monitor and anticipate pollution levels (Castelli et al., 2017), (Park et al., 2013). Another study (Miles et al., 2018) demonstrated a model that uses an IoT-based Decision Support System to detect pollution levels and implement successful pollution control strategies. The current proposal also integrates fundamental traffic simulations with spatial data in order to forecast traffic-related pollution levels.

Water management in crowded populations is a difficult subject to organize properly (Polenghi-Gross et al., 2014). Moreover, large groups and urbanization provide a number of difficulties, including an aging water system, exorbitant maintenance expenses, new pollutants, and so on (Polenghi-Gross et al., 2014), (Hou et al., 2013). Appropriate water management methods must be established as a result of such concerns. ICT technologies, according to some experts, have the potential to enhance the hygiene and sanitation throughout the world (Corbett & Mellouli, 2017), (F. Sun et al., 2017). (Corbett & Mellouli, 2017), for example, developed a conceptual framework, which promotes the IS in ecological smart city development. Three separate connected concerns, notably management, government, and sustainability, were described in the framework.

Another important challenge in sustainable smart cities is waste management. This problem has a direct impact on the quality of life of city dwellers (An et al., 2019). Several research have looked on IoT-based waste management (Anagnostopoulos et al., 2015), (Oralhan et al., 2017), (Rybnytska et al., 2018). In a study by (Anagnostopoulos et al., 2015), on the basis of sensor data, a dynamic trash collecting strategy was suggested. Given the existence of severely contaminated trash collection, which might harm people' quality of life, the proposed study primarily focused on high waste collecting places, such as colleges, hospitals, and institutions.

4.2.6. Smart Building

Smart living include smart buildings, education, tourism, wellness, and community security, all of which have the potential to enhance residents' quality of life. One of the key issues in smart living is crime prevention, which has an impact on improving country development (An et al., 2019). Several research have looked into public safety utilizing ICT techniques (Breetzke & Flowerday, 2016), (Cilliers & Flowerday, 2017). For instance (Breetzke & Flowerday, 2016), in South Africa, a crowd-sourcing approach was suggested and tried with community involvement. The usefulness of an IVR was investigated, and it was discovered that this technology might be a helpful technique for residents reporting concerns about safety. According to another study (Cilliers & Flowerday, 2017), IVR is a highly beneficial method since it is simple to understand and reliable.

Healthcare concerns are also necessary to study measuring the quality of life of people in smart cities, according to certain studies (Hussain et al., 2015), (Pramanik et al., 2017), (Thibaud et al., 2018). (Hussain et al., 2015) established a paradigm for citizens health management for older and handicapped inhabitants of smart cities utilizing actual surveillance. Inside a digital environment, people's health was examined using urgent assistance for their extra caution and requirements. (Pramanik et al., 2017) demonstrated a healthcare-connected business plan as part of their strategy for even a big data-enabled Smart Healthcare System. This system reduced health-care expenditures while also improving communication and service performance.

According to the author (Vincent, 2006), education services have a significant influence on the quality of smart cities inside a local infrastructure. An integrated system on educational infrastructure was proposed in a research by (Ortiz-Fournier et al., 2010) to create a powerful business plan and tackle most of the other region's challenges.

The authors (Gretzel et al., 2015) presented a STE for developing, administering, and distributing smart tourist services that takes full advantage of smart technologies. Tourism stakeholders were involved in major knowledge management and value co - production in this ecosystem. The planned STE also presented significant potential for creative marketing strategies and added value to the co - creation environment, as well as technical advancements.

The notion of smart buildings has gained a lot of traction, especially among people, who are using mobile phones to communicate (An et al., 2019). The NomaBlue model, for example, was proposed in the research as a way to allow smart nomadic data collecting using Bluetooth technology (Boukhechba et al., 2017). NomaBlue might be utilized for marketing in the context of tailored shopping, thanks to its related exploration capability. One of the most significant advantages of this technology is that it does not need a constant Internet access or pre-defined regional datasets.

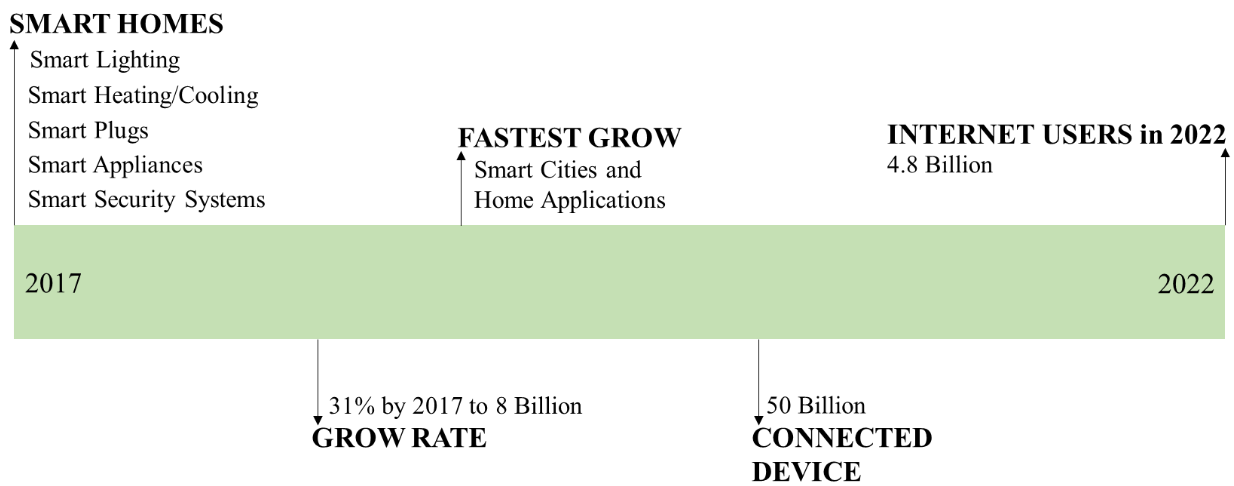


Figure 9 The number of smart gadgets linked to the Internet until 2022 (Gagliordi, 2018).

4.3. Analysis of the Architecture of Smart Cities

It is critical to consider the city's setting while designing smart city structure. Therefore, a perception of environmental circumstances to which individuals are continuously exposed must be defined. With all that in mind, this section on IoT, Big Data, and Cloud Computing that are the main pillars of smart solutions emphasizes the three-dimensional architectural idea. Those pillars are extremely extensive, because they assist communities and residents in dealing with large-scale network and storage sources.

4.3.1. IoT

After the development of Internet technology in the 1990s, the term "Internet of Things (IoT)" was created in 1999 (Alavi et al., 2018), (Ashton, 2009). According to (Sundmaeker et al., 2010), the Internet of Things (IoT) is a worldwide platform that delivers enhanced services by linking physical and digital contents via ICT. IoT encompasses Internet-based technology combined with requirement specification or activities, implying that even bigger ideas of control systems may be managed via IoT devices based on customers' preferences (Perera et al., 2015), (Perera et al., 2014). IoT allows objects to "speak" to each other at the same time utilizing a variety of approaches such as smart technology, connected system, and sensors. In fact, the Internet of Things is a way to make many classic communication equipments "smart." Sensor use with IoT has also been effectively increased in many sectors in recent years, thanks to the growth of cloud computing. Furthermore, 50-100 billion devices will be connected to the Internet by the end of 2020, utilizing different ICTs (Sundmaeker et al., 2010). Figure 10 depicts the utilization of smart home apps as well as the expected rise in linked smart devices by 2022.

According to a research by (Al-Fuqaha et al., 2015), the Internet of Things is divided in two categories: implementation and technical platforms. Users engage with actual historical data using various sensory mechanisms in the technology platform (Jalali et al., 2015), as well as the technology platform describes IoT network design depending on the referred channel, notably, QoS (Jin et al., 2012). Furthermore, research teams have mostly been embedding them to smart devices with the use of IPv6-enabled architecture (Jung et al., 2013), adaptable IoT classified architecture prototypes, and smart grid IoT systems for energy management (Miao Yun & Bu Yuxin, 2010), (Ghasempour, 2016), (Khajenasiri et al., 2017). The application platform, on the contrary, has been quickly developing and investigated in many published papers (Petrolo et al., 2014), (Cesana & Redondi, 2017), (Salehi & Burgueño, 2018). Scientists have used IoT in a variety of contemporary city applications, including cyberville, digital city, information city, smart city, and wired city, for example (Mohanty et al., 2016). Additionally, several Iot devices have been created recently, including IP cameras (González García et al., 2017), smart wheelchairs (Rashid et al., 2017), building information management, and cloud-based early warning systems (J. Wang et al., 2017), and WoT (Gyrard & Serrano, 2016), (Gyrard et al., 2016).

Different methods to smart city implementations have been presented as a result of fast advancements in IoT technology. Studies have extensively highlighted the potential of IoT in the construction of ecological smart cities. IoT technologies are used in smart cities and smart buildings, which are two key application domains.

4.3.2. Big Data

The cloud must be utilized as a foundation for offloading a large amount of data, which are often created by IoT devices, in order to process it. Furthermore, IoT data may be represented as big data, which could be used in a Cloud Computing context to solve the challenges of IoT-generated big data (Wazid et al., 2019).

Cloud-based IoT-based big data has various benefits, and its function opens up some possibilities (Cai et al., 2016), (Marjani et al., 2017), (Jindal et al., 2018). For example, data in an IoT environment, which is also generated by smart IoT devices, may expand exponentially over time. Exabytes of data might be collected with the help of big data technologies, which could then be processed effectively and rationally to make the best judgments possible. Whenever interacting with large volumes of data, traditional techniques are not cost-effective, and they are not suited for data processing and storage systems; consequently, big data created by IoT devices might assist these instances.

Because of the expanding volume of data, smart city services are growing. As a result, such massive volumes of data, or big data, generated by IoT, are the fundamental core of city services (Hashem et al., 2016). Big data is defined by its volume, velocity, and variety of data formats (Gani et al., 2016), (Khan et al., 2014). A city might gain valuable perspectives from considerable data collected from many sources using big data technologies (Hashem et al., 2016).

Nowadays, a huge amount of data is generated by many data sources like as smart phones, computers, global poisoning platforms, sensors, and cameras. As a result, traditional data mining approaches struggle to store and analyze data effectively (Hashem et al., 2016). Big data, on the other hand, may be utilized to extract useful information from the massive amounts of data created by detectors and gadgets. Furthermore, excellent big data utilization may be a major component in the success of organisations and local areas. In addition, owing to the presence of massive computational storage facilities for processing this data inside smart cities, the implementation of big data in smart cities offers numerous benefits and limits. Nevertheless, such big data technology's reliance on Cloud Computing and IoT services is now one of the most major advantages (Hashem et al., 2016).

The majority of big data implementations in smart cities require intelligent networks with meaningful interconnections between items and inhabitants' devices, including such smart phones and automobiles. Therefore, such smart networking must be capable of efficiently transferring gathered data through supplies and responds back to individuals. As a result, QoS is critical for actual big data technologies in smart cities (Hashem et al., 2016).

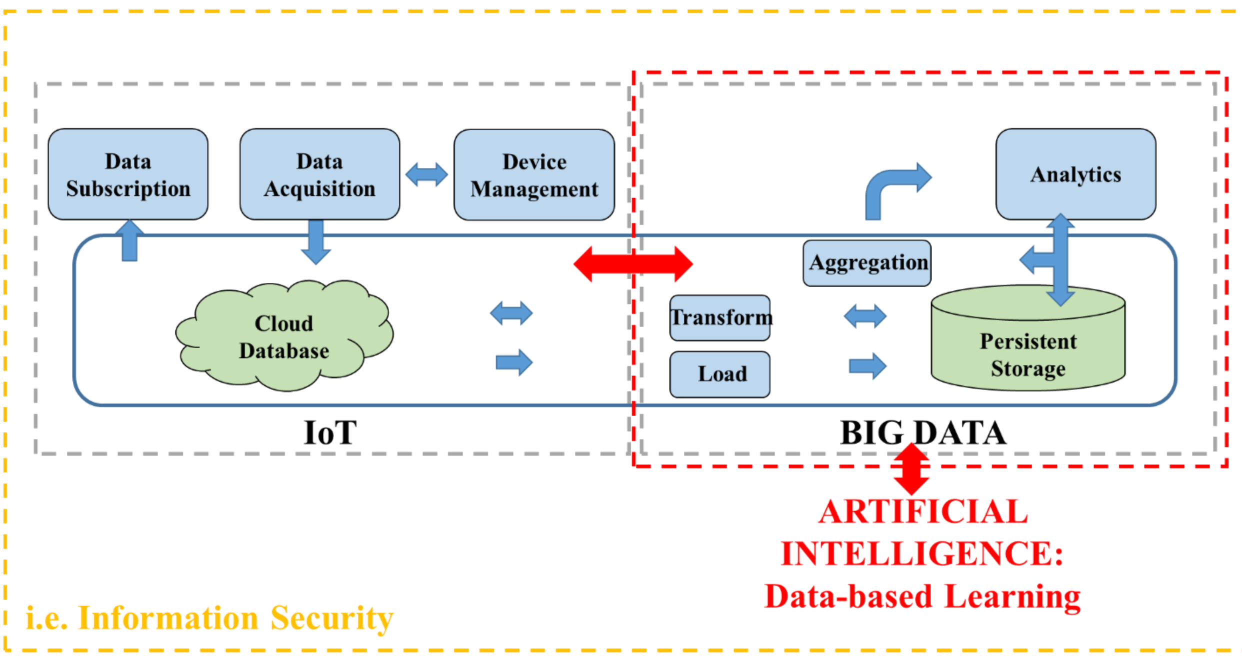


Figure 10 IoT, Big Data, and Cloud Computing: What's the Connection? (by author).

4.3.3. Cloud Computing

Cloud Computing is a viable option for processing large amounts of data. Cloud computing is a sort of computing that provides users with access to a shared platform of computer resources. Cloud computing, for example, may provide a number of advantages to both businesses and people in terms of capital costs and expenses (Subramanian & Jeyaraj, 2018). According to the sources (Perera et al., 2015), (Wazid et al., 2019), and (Subramanian & Jeyaraj, 2018), Figure 11 depicts the connection between IoT, Big Data, and Cloud Computing. I've combined these concepts and come up with this figure.

Users of Cloud Computing benefit from a network-based environment that allows them to share information and do computations from a single place (Subramanian & Jeyaraj, 2018). Based on the NIST (Mell & Grance, 2011) Cloud Computing specification, Cloud Computing is a sort of platform that enables adequate Internet connection, as well as a common pool of customizable grids, data storage, software, and servers that can be instantly released by interaction with a supplier.

Because various security challenges and risks occur in data centers in physically dispersed areas, Cloud Computing customers do not know the actual location of their important data. Furthermore, due to the rapid spread of threats, common security solutions like firewalls or host-based antivirus software are unable to provide adequate protection systems in virtual servers (Subramanian & Jeyaraj, 2018).

Cloud Computing gives companies with rapid access to physical components, as well as a low initial investment and low-cost maintenance (Marston et al., 2011). Cloud computing is also regarded as a powerful accelerator that boosts administrative speed and effectiveness (Battleson et al., 2016).

In Cloud Computing, there are two main views: technical and customer viewpoints (Battleson et al., 2016). Security, virtualization, architecture, and pricing structures, for example, are critical from a technological standpoint (Paquette et al., 2010). Nevertheless, in terms of client perspectives, the emphasis is on client obstacles and possibilities (Battleson et al., 2016). Transaction costs, privacy, and security issues were discovered inside the cloud architecture in a research by (P. Chen & Wu, 2013). Another research (Battleson et al., 2016) looked at how Cloud Computing may help with dynamic capacities.

Some researches make advantage of the cloud computing and internet of things (IoT) connectivity. The research, for instance, presents a novel platform for Cloud Computing capability and assistance of smart connectivity and real-time applications for smart cities (Suciu et al., 2013). A framework for data acquired from extensively dispersed, diversified, restructured, virtual and physical devices was also given in this work. Cloud services might administer, analyze, and regulate this architecture autonomously.

4.4. Literature Matrix: Applications and Previous Studies

I create a thorough literature matrix for smart city applications regardless of previous research. Depending on analyses of smart city topics, suggested techniques, advantages, and limits, a comprehensive arrangement of relevant scientific research is carried out. Table 4 categorizes a total of 25 scientific publications between 2012 and 2021 to give a concise yet inclusive matrix.

Table 4 Previous Smart City applications and scientific studies (by author).

Reference	Year	Themes	Proposed method	Benefits	Limitations
(Lazaroiu & Roscia, 2012)	2012	Smart economy, smart environment, smart energy, smart mobility, smart governance	Fuzzy logic	Both decision-makers and individuals will benefit from a greater understanding and ease of usage	Information that is non-homogeneous and contains a huge amount of data
(Yamagata & Seya, 2013)	2013	Smart land-use, smart energy, smart transportatio n	Simulation and scenario analysis	When compared to the dispersion domain, a compact urban layout minimizes	Data-intensive and computationally challenging

				household power usage	
(Galán-García et al., 2014)	2014	Smart traffic lights, smart signals	Cellular automata and neural network	Smart signals are a robust and simple technique for simulating road traffic in a city	Computer programs with a high level of sophistication
(Elmaghraby & Losavio, 2014)	2014	Smart security, smart privacy	GPS tracking device	A significant amount of private data is accessible at a cheap cost	It really can result in erroneous leads and rash responses on the part of certain falsely accused individuals and populations
(Anagnostopoulos et al., 2015)	2015	Smart waste management	Simulation and dynamic waste collection architecture	In high-priority regions, continuously adapts to variations in trash output	Unexpected circumstances involving waste creation are a source of concern
(Ben Letaifa, 2015)	2015	Leadership, democratic participation	Longitudinal analysis and data collection	A systematic framework for smart cities	N/A

(Calvillo et al., 2016)	2016	Smart energy, smart grid	Energy system modeling	One of the most cost-effective strategies for creating intelligent and also more functional communities	System variable choices and energy limitations
(Yeh, 2017)	2017	Smart citizens, smart living	Self-administered questionnaire	Becomes involved with smart city initiatives	Data collecting demographics are distributed in an unofficial manner
(Palomo-Navarro & Navío-Marco, 2018)	2018	Smart governance	PEST (Political, Economic, Social and Technological) analysis	Major developments in city government are discussed, as well as increasingly concrete complicated networking as well as system performance	N/A

(de M. Del Esposte et al., 2019)	2019	Inter smart city	Smart city simulator	Adaptable to changing workloads by scaling up and down horizontally	Other smart city scenarios aren't integrated, and cross-domain studies aren't possible
(Curzon et al., 2019)	2019	Smart privacy	A detailed review of existing privacy enhancing technologies	N/A	N/A
(Elsaeidy et al., 2019)	2019	Smart city infrastructure	Restricted Boltzmann Machines (RBMs)	Capability to unsupervised learn greater features from raw data as well as handle real-time data visualization provided by smart meters and devices	Inherited security issues, with cyber-attacks and DDoS assaults posing particular dangers
(Nilssen, 2019)	2019	Smart urban innovation	Analytical model	N/A	N/A
(Desdemoustier et al., 2019)	2019	Smart governance	Data collection and a typology of municipal understandings	N/A	The research never guarantees to accurately capture the

					intricacies of municipal comprehension
(Roque-Cilia et al., 2019)	2019	Smart transportatio n	Wireless Dynamic Sensor Network (WDSN)	In smart cities, this is useful for determining the position of nodes	There are a variety of impediments that can obstruct line-of-sight signals, as well as environment issues
(Dameri et al., 2019)	2019	Smart urbanization	Qualitative Data Analysis	Practitioners will find this useful	Although the study did not cover several problems that are outside its scope, they are intriguing for further research
(Sepasgozar et al., 2019)	2019	Smart urbanization	Urban service technology acceptance model (USTAM)	Supports the initiative to build smart cities in poor nations with both empirical and conceptual assistance	N/A
(Abbate et al., 2019)	2019	Smart business,	Fuzzy set qualitative	One of only a few studies	The current study's small

		smart technology	comparative analysis (fsQCA)	focusing on Business Model (BM), which goes beyond a single study, providing several avenues for future research	sample size precluded any additional hypothesis testing of fuzzy analysis
(Wu et al., 2020)	2020	Smart healthcare	Econometric model regression and propensity score matching	Improved urban medical treatment and health	Data availability
(Prasad & Alizadeh, 2020)	2020	Smart policy	Mapping analysis	Shed lights on the existing gaps in the North-centric smart city research	A need for future empirical studies to assess smart city vision statements
(Eichelberger et al., 2020)	2020	Smart tourism	Questionnaires	Offer rich data that is very helpful for gaining an understanding	Restricting its result generalizability

(Clement & Crutzen, 2021)	2021	Smart policy	Review of the literature	Better explain the dynamism of the policy subsystem	Limited with its consideration for the policy subsystem and the key political actors in the policymaking process
(Razmjoo et al., 2021)	2021	Smart policy	Review of the literature	N/A	N/A
(Z. Chen, 2021)	2021	Smart ecology	Ecological strategy	Enable the smart city to develop healthily and well	N/A
(Kashef et al., 2021)	2021	Smart surveillance	Smart city surveillance system	Enhance smart cities' safety and security	N/A
(Thornbush & Golubchikov, 2021)	2021	Smart energy	Review of the literature	Presents an environmentally-adapted perspective on the city	N/A

Table 4 is based on the literature list, which is produced in conjunction with the review paper by (Kirimtat et al., 2016). As a result, and as shown in Table 4, information visualizations from prior studies concerning smart cities are supplied, and the next part includes a thorough discussion of the published articles.

4.4.1. Discussion on the Results of the Previous Studies

Highlighting the role of smart cities in the research community and in practical uses, I gather important research from the current literature between 2012 and 2021 and summarize them in Table 4. Figure 12 depicts the publication chronology for these researches. Since the issue is now highly popular, it is evident from this scatter plot diagram that available literature on smart cities are rising, particularly in 2019, 2020 and 2021.

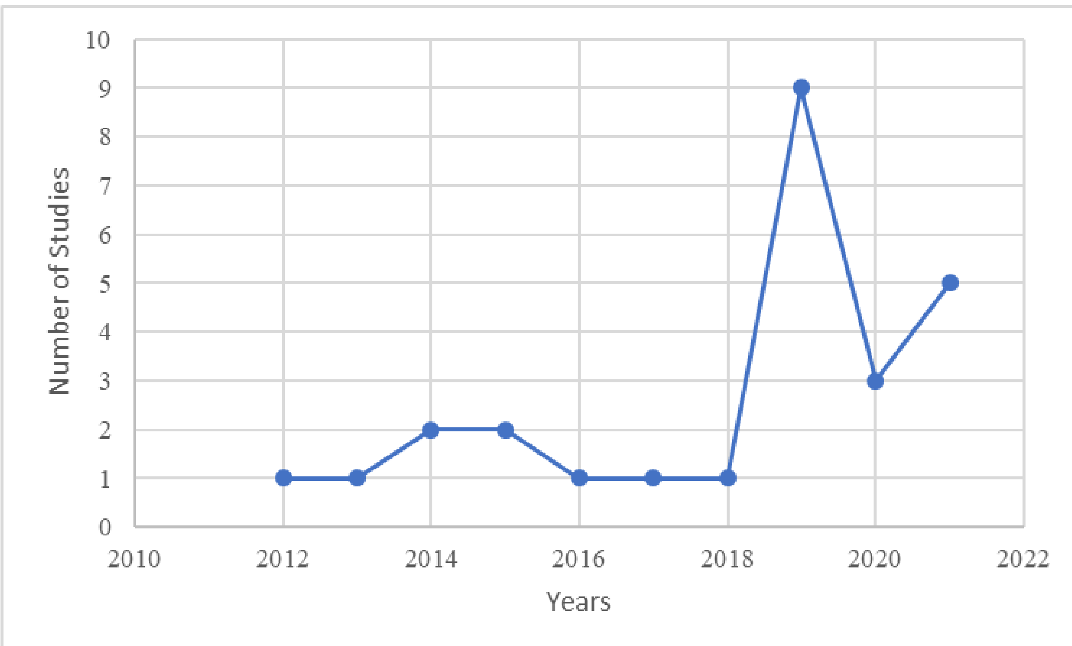


Figure 11 The number of researches published between 2012 and 2021 according to ISI WOS from Table 3 (by author).

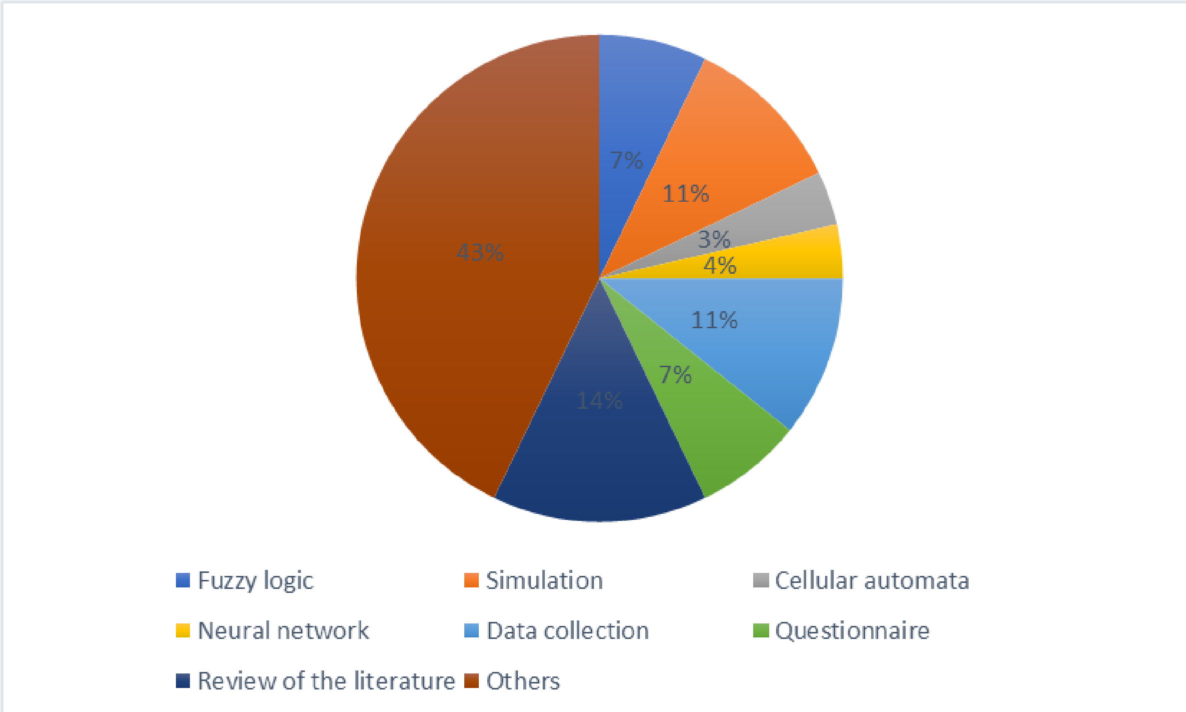


Figure 12 The frequency of recommended techniques in ISI WOS research from Table 3 (by author).

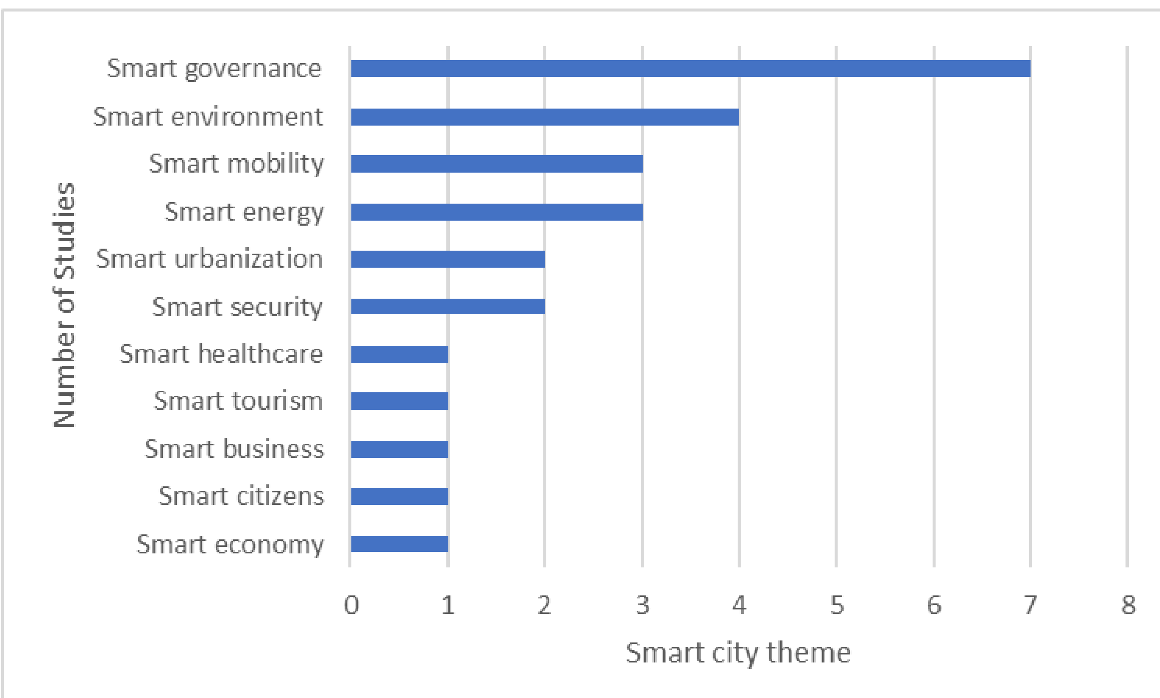


Figure 13 The number of major smart city themes found in ISI WOS research from Table 3 (by author).

Figure 13 depicts an important criterion for categorizing the studied methods in existing researches. The majority of research focuses on computer science technique, which includes fuzzy logic, simulation, cellular automata, and neural networks. Smart governance, smart transportation, smart energy, smart environment, smart urbanization, smart security, smart waste management, smart technology, smart business, smart people, smart living, and smart economics are among the smart city themes explored in Figure 14. The most studied smart city theme within these papers is smart governance (Lazaroiu & Roscia, 2012), (Ben Letaifa, 2015), (Palomo-Navarro & Navío-Marco, 2018), (Desdemoustier et al., 2019), and the second most studied smart city themes include smart environment (Lazaroiu & Roscia, 2012), (Yamagata & Seya, 2013), (Elsaeidy et al., 2019), which are generally based on sustainability issues. To name the most detailed example among these studies, the authors (Lazaroiu & Roscia, 2012) researched smart city indices by developing a sustainable city model. Moreover, the computation of the indices mentioned in this study included smart economy, smart environment, smart energy, smart mobility and smart governance. In this study, the proposed framework used a fuzzy logic method to estimate "the smart city".

To generalize these findings, a perfect smart city would represent the most preferred themes and provide services relevant to these areas. The concept of smart floating cities seems to be the most likely concept discovered in the literature to have these qualities (Kirimtat et al., 2015a). Any floating city or colony has as its objective the exploration of alternative living places as well as the prevention of human suffering throughout the planet. To make a floating city smart and sustainable, certain smart city ideas need undoubtedly to be used.

5. Problem Definition

Scientists, architects, and designers consider city planning to be a difficult design issue, therefore evolutionary algorithms might be employed to solve it by optimizing residents' needs. In this dissertation, I evaluate the outcomes of four different evolutionary algorithms, mainly jDE, JcGA-DE, MOHS, and NSGAII, in three different case studies of the proposed smart floating city through optimizing conflicting objective functions.

5.1. Case Study 1: Accessibility Development of the Smart Floating Cities

This section covers the foundations of the conceptual model and system design. This section also consists mostly of design variables and objectives, which are the fundamental units of the parametric model. The parametric model is produced using the Rhino3D program as well as the Grasshopper plug-in.

5.1.1. Decision Variables

In the first case study, there are a total of 64 control parameters (p_{ij}) for maximizing the design problem. These 64 parameters are determined individually, and they are in the range of 0 to 1. As a percentage, each one of them symbolizes the role of one function (residential, agricultural, green, and public spaces). In addition, the following are explanations of the expressions used throughout the parametric model:

$p_{ij} = percentage\ of\ function\ (i)\ in\ cluster\ (j)$

$i = 1,..,4\ (residential, agricultural, green, public)$

$j = 1,..,16$ (clusters)

$VC = Visual\ Comfort$

A $=\ Accessibility$

$o_x = x\ coordinate\ for\ offshore$

$o_y = y\ coordinate\ for\ offshore$

$c_x = x\ coordinate\ for\ coastline\ of\ Urla$

$c_y = y\ coordinate\ for\ coastline\ of\ Urla$

$r_x = x\ coordinate\ for\ residentials$

$r_y = y\ coordinate\ for\ residentials$

$a_x = x\ coordinate\ for\ agricultural\ areas$

$a_y = y\ coordinate\ for\ agricultural\ areas$

$g_x = x\ coordinate\ for\ green\ areas$

$g_y = y\ coordinate\ for\ green\ areas$

$p_x = x\ coordinate\ for\ public\ areas$

$p_y = y\ coordinate\ for\ public\ areas$

$a_{ab} = accessibility\ between\ a\ and\ b\ functions$

$(for\ \forall\ a\ and\ b)$

$r_{r,o} = remoteness\ between\ residential\ blocks\ and$

$offshore$

$r_{a,c} = remoteness\ between\ agricultural\ and\ coast$

$r_{g,c} = remoteness\ between\ green\ areas\ and\ coast$

$r_{r,c} = remoteness\ between\ residential\ blocks\ and\ coast$

$r_{r,g} = remoteness\ between\ residential\ and\ green$

$r_{r,a} = remoteness\ between\ residential\ and\ agrcicultural$

$r_{r,p} = remoteness\ between\ residential\ and\ public$

5.1.2. Objective Functions

The smart floating city's objective functions are defined as enhancement of visual comfort and accessibility. As a result, the objective functions are as follows:

Objective Function 1: Visual Comfort

With objective function 1, I am attempting to maintain the distance between residential areas and offshore as small as feasible in order to provide people with visual comfort. As a result, the distances between the equations (1-4) are computed as follows:

$$r_{r,o} = |rx - ox| + |ry - oy| \tag{1}$$

$$r_{a,c} = |ax - cx| + |ay - cy| \tag{2}$$

$$r_{g,c} = |gx - cx| + |gy - cy| \tag{3}$$

$$r_{r,c} = |rx - cx| + |ry - cy| \tag{4}$$

I am retaining a certain variable in a specified interval as an alternative to maximizing or minimization of a variable. To maintain proximity between residential areas and coastal regions, for instance, the distance between them should be between 0 and 1500 meters. The “Walk Score” website (*Walk Score*, 2021) was used to determine the limit values. As a result, specific meter intervals are as continues to follow:

$$0 < r_{r,o} < 1500 \tag{5}$$

$$300 < r_{a,c} < 1500 \tag{6}$$

$$300 < r_{g,c} < 1500 \tag{7}$$

$$300 < r_{r,c} < 1500 \tag{8}$$

Additional equations (9-12) are specified as follows, depending on the intervals provided in equations (5-8) above:

$$r_1 = \max(0, \min\left(1, \frac{r_{r,o} - 1500}{0 - 1500}\right)) \tag{9}$$

$$r_2 = \max(0, \min\left(1, \frac{r_{a,c} - 1500}{300 - 1500}\right)) \quad (10)$$

$$r_3 = \max(0, \min\left(1, \frac{r_{g,c} - 1500}{300 - 1500}\right)) \quad (11)$$

$$r_4 = \max(0, \min\left(1, \frac{r_{r,c} - 1500}{300 - 1500}\right)) \quad (12)$$

r_1, r_2, r_3, and r_4 reflect four distinct degrees of separation between functions, which I label as residential, agricultural, green, as well as public. For example, r_1 is the distance between residential areas and the seashore.

Objective Function 2: Accessibility

The important aspect with this objective is the distances between functions, including the minimum distance between green and built up areas, which is between 300 and 1000 meters. The following are the explanations for the equations:

$$r_{r,g} = |rx - gx| + |ry - gy| \quad (13)$$

$$r_{r,a} = |rx - ax| + |ry - ay| \quad (14)$$

$$r_{r,p} = |rx - px| + |ry - py| \quad (15)$$

$$300 < d_{a,b} < 1000 \quad (16)$$

$$a_{ab} = \max(0, \min\left(1, \frac{r_{a,b} - 1000}{300 - 1000}\right)) \quad (17)$$

$$for\ \forall\ a\ and\ b.$$

5.2. Case Study 2: Cuboid Open TSP in a Smart Floating City

Inside the smart floating city, the challenge of the suggested model is framed as finding a suitable balance of cost-effective platform building and efficient transit networking. In this scenario, there are three separate decision variables. Grasshopper3D, a Rhino3D plug-in, was used to generate the whole parametric model. In the following part of this section, the decision variables are analyzed.

5.2.1. Decision Variables

Figure 15 depicts a cuboid, which is a geometrical form with three-dimensional coordinates, specifically x, y, and z that equal to the height, length, and width of a cuboid. Rather than a flat plane, nodes/platforms throughout given scenario are on a cuboid surface for cuboid open TSP. For cuboid open TSP, the distance between nodes/platforms is computed using Euclidean distances depending on x, y, and z coordinates. The following formula can be used to compute the distance between the nodes:

$$d_{i,j} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2 + \left(z_i - z_j\right)^2} \qquad (18)$$

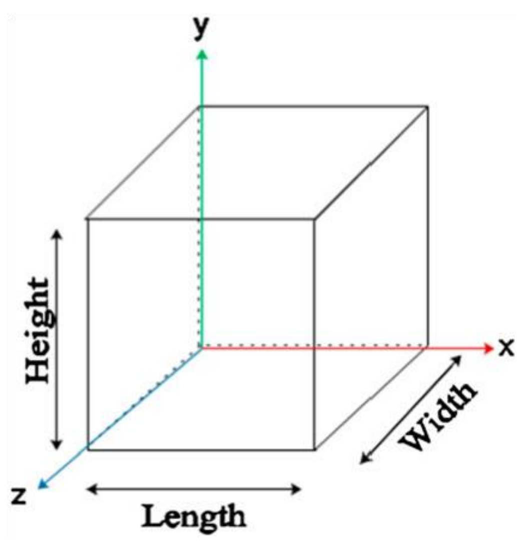


Figure 14 Three-dimensional cuboid (by author).

The decision variables in this problem are the random seed number and the number of nodes/platforms. The idea behind the variable platform numbers is that I'm looking for Pareto - optimal solutions below sea level in which a small number of nodes have enough space to go deeper under the sea level, while a large number of platforms are distributed randomly near or below sea level, causing a conflict between two goals. It's worth noting that the z coordinate denotes the cost of platforms below sea level. As a result, platforms that are buried deeper have greater platform expenses. Grasshopper3D, a Rhino3D plugin, is used to build the parametric model. The number of platforms, which varies between 100 and 1000, is the first decision variable in the parametric model, and the random seed for insertion, which varies between 0 and 100, is the second. Table 5 lists them all in detail. Both algorithms operate on a continuous domain, and after calculating the first decision variable, the number of platforms is adjusted to an integer number.

Table 5 The generative model's decision variables (by author).

Decision Variable	Range	Variable Type
Number of nodes	$s^{min}, s^{max} = [100, 1000]$	integer
Random seed	$s^{min}, s^{max} = [0, 100]$	real

Table 6 displays the chromosomal representation for individuals in the population with a size of NP for the algorithms in order to clarify the chromosome representation of individuals in the population with a size of NP.

Table 6 The representation of chromosomes (by author).

Individual	Number of platforms	Random seed number	$s_{i,j}$ implies $x_{i,j}, y_{i,j}, z_{i,j}$	$s_{i,j}$ also implies $\pi_{i,j}$
$s_{i,j}$	$s_{1,1}$	$s_{1,2}$	$x_{1,1}, y_{1,1}, z_{1,1}$	$\pi_{1,2}$
	$s_{2,1}$	$s_{2,2}$	$x_{2,1}, x_{2,1}, x_{2,1}$	$\pi_{2,2}$
	$s_{3,1}$	$s_{3,2}$	$x_{3,1}, x_{3,1}, x_{3,1}$	$\pi_{3,2}$
	.	.	.	.
	.	.	.	.
	$s_{NP,1}$	$s_{NP,2}$	$x_{NP,1}, x_{NP,1}, x_{NP,1}$	$\pi_{NP,2}$

The i^{th} individual in the initial population NP, as well as the individual j^{th} decision variable, is represented by the individual $s_{i,j}$. Using Grasshopper3D, I create a zone (in reality, a cuboid) beneath sea level for each individual in the population. Two decision variables, seed numbers, and the number of nodes/platforms are linked to Grasshopper3D before connecting 3D coordinates area description to TSP script, which is presented in Pseudo Code 1.

5.2.2. Objective Functions

Grasshopper3D builds the x, y, and z coordinates for each individual in the initial population and produces the Euclidean distance through using seed number. The TSP script from the Pseudo Code 3 that is loaded from Rhino3D in Python description in Grasshopper, can be used to build a permutation $\pi_{i,j}$. The TSP script determines the permutation and its objective function numbers in such a way that it starts at node 1 and computes the traveling distance by choosing the nearest node with the shortest distance among all nodes in a greedy manner.

Pseudo Code 3. The TSP pseudo-code, imported from Rhino3D.

```
Import rhinoscriptsyntax

Import Rhino

firstPt = allPts[startIndex]

del allPts[startIndex]

visitedPts = [firstPt]

def TravelingSalesMan(fromPt, i):

    nextIndex = Rhino.Collections.Point3dList.ClosestIndexInList(allPts, fromPt)

    nextPt = allPts[nextIndex]

    visitedPts.append(nextPt)

    del allPts[nextIndex]

    if(i > 0)
```

$\boldsymbol{TravelingSalesMan}(nextPt, i - 1)$

$\boldsymbol{TravelingSalesMan}(firstPt, iterations)$

$a = visitedPts$

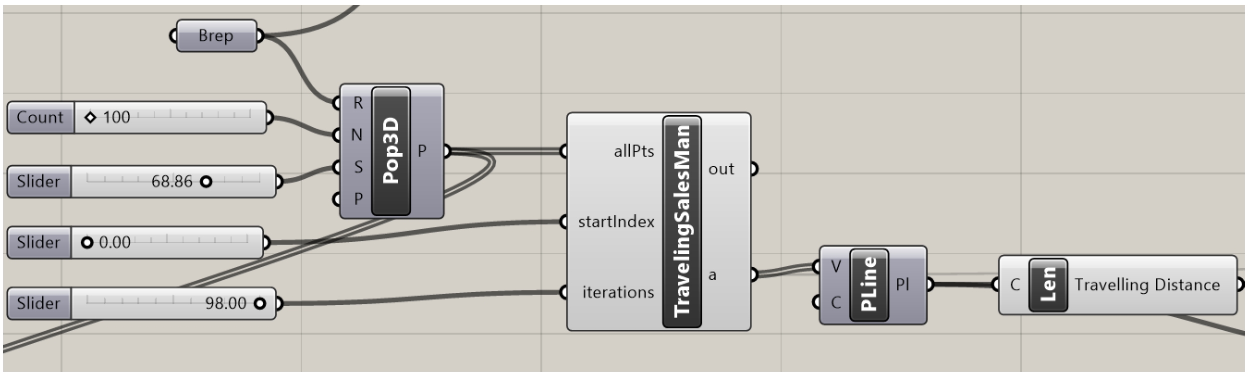


Figure 15 The defined parametric model in Grasshopper3D (by author).

In terms of the platform cost, which is determined by the z coordinates of the nodes, which symbolize either breakwaters and platforms under water level. The expenses in this problem are broken down into two categories: breakwater costs and platform costs. There are three main types of floating breakwaters, according to FDN Engineering (*Floating Constructions*, 2020), which are primarily T-Block, U-Block, and Heavy Duty U-Block, as shown in Table 6. T Blocks are utilized in marine environments with water depths of up to 6 meters and wave heights of up to 1.1 meters. For more extreme situations, such as sea depths of up to 12 meters and wave heights of up to 2.5 meters, U-Block is advised. Heavy Duty U-Blocks are breakwaters designed to withstand significantly harsher circumstances. Nevertheless, because it is an average type, I consider U-Block floating breakwater types in this case study.

Table 7 A rough estimate of the expenses of constructing a breakwater, including anchorage and installation, but omitting VAT (*Floating Constructions*, 2020).

	T-Block	**U-Block**	**Heavy Duty U-Block**
Length	up to 20 m	up to 30 m	50+ m
Width	3 – 4 m	4 – 7 m	7 – 18 m
Height (total)	3 – 4 m	4 – 7 m	7 – 18 m
Water depths	up to 6 m	6 – 12 m	> 12 m
Wave heights	up to 1.1 m	1.1 – 2.5 m	> 2.5 m
Cost estimate	3.000 € / meter	5.000 € / meter	10.000 € / meter

Figure 17 is an example of nodes/platforms under sea level, with some being quite close to the surface and others being far deeper. Because the z coordinates define the water depths, I calculate the cost of platforms using the entire z coordinates as follows:

$$PC = \text{Total } z\ coordinates\ of\ the\ platforms * 5000\ euro/meter \quad (19)$$

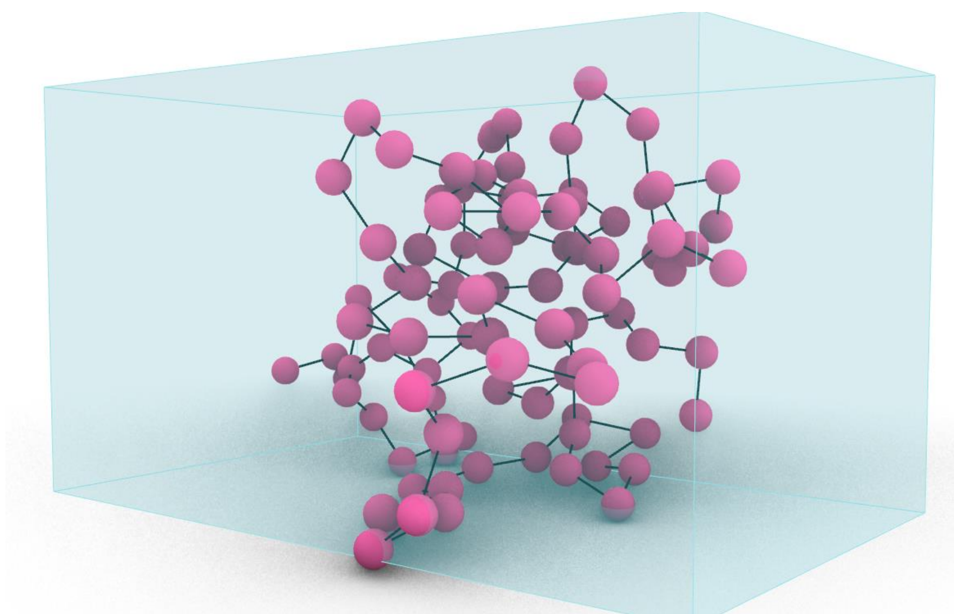


Figure 16 Grasshopper visualization used to depict the nodes (platforms) below sea level in Rhino 3D (by author).

5.3. Case Study 3: An Amorphous Shading Device Integrated Smart Building in a Smart Floating City

The optimization components described for the parametric model of the amorphous shading device constitute the performance evaluation-based optimization model. In the computational modeling environment, the amorphous shape of the shade panels is first constructed parametrically. Decision variables, constraints, and objective functions are the optimization components that are examined for the specific architectural issue. Thus, every decision variable has a set of parameters that impact the geometry of the proposed shading device in different ways.

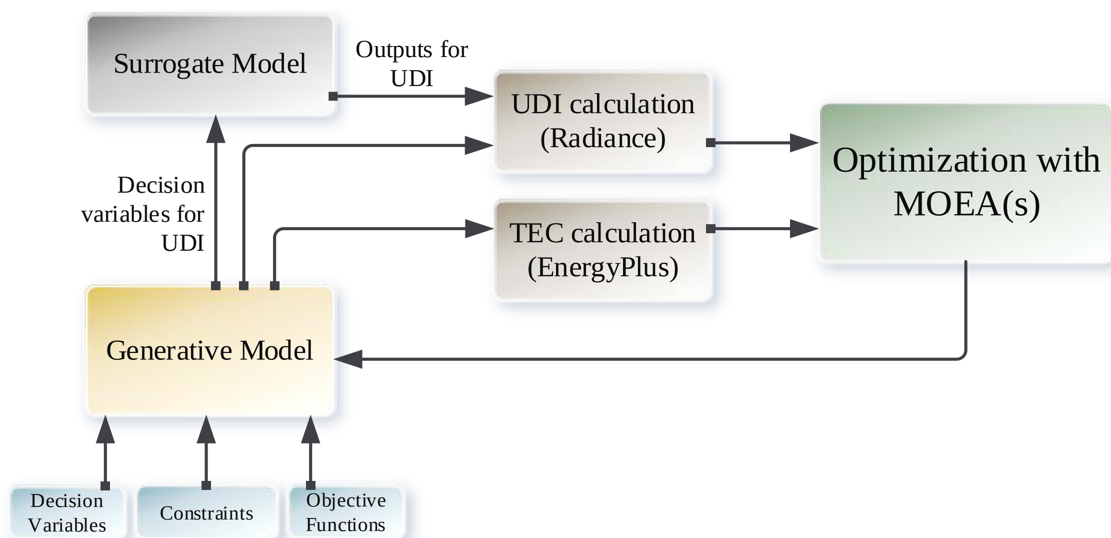


Figure 17 The amorphous shading device's principal workflow includes smart building improvement. (by author).

Energy and daylight simulation models are given independently as objective functions depending on the complex geometries of the amorphous shading device. The energy simulation engine calculates TEC, whereas the daylight simulation engine calculates the average value of UDI points. In addition, I use surrogate modeling by doing regression analysis of UDI points placed in the sample office area. Lastly, performance evaluation-based optimization is applied to the complex design issue utilizing two different MOEAs. The procedure for the third case study is shown in Figure 18.

5.3.1. Decision Variables

The sample office building that has six closed office rooms with south facades, is built in algorithmic modeling environment before defining the geometry of the amorphous shading panels that have free-form parametric geometries only restricted by the bounds of the parameters. The primary office room that is in the middle of all the other 6 office rooms, has proportions of 7.50m width, 10.34m length, and 2.50m height, while the glazing section that is on the south façade, has proportions of 1.50m height and 7.50m length. Second, the shading device's shape was numerically designed based on point motions on panels in the X and Y axes, as well as rotation angles that are also decision variables. Every panel shape transforms as the parameter sliders are adjusted between defined real numbers, and the simulated results are immediately influenced. In addition, through optimizing the shape of the shading device with a multi-objective method, I am attempting to reduce TEC, comprising heating and cooling energy consumptions, and optimize UDI in the parametric model. Table 8 contains the design problem formulation, decision variables, and their interpretations, as well as a visual depiction of the design variables in Figure 19.

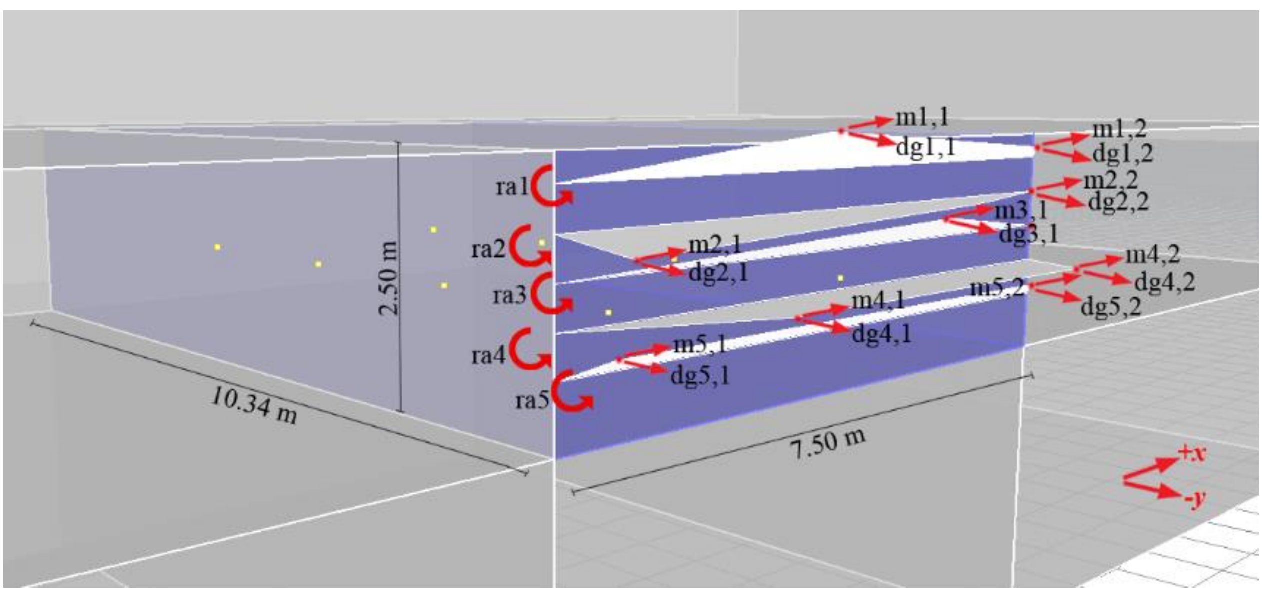


Figure 18 Representation of the shading panels and their design variables (by author).

In the third case study, 25 decision variables are provided depending on the geometry of the shading panels. In this situation, there are a large number of decision variables, and study reveals that a large number of decision variables slows down the search process. Regarding this, the huge number of variables, in addition to the stochastic approach of the optimization process, adds to the uncertainty, however the method in this case study is still effective in discovering huge and complicated design spaces.

Furthermore, "dg" stands for "distance from glazing," "ra" stands for "rotation angle," and "m" stands for "movement." They are both continuous variables and real values. Table 7 also explains this that $\mathbf{dg_{1,1}}$, $\mathbf{dg_{1,2}}$, $\mathbf{dg_{2,1}}$, $\mathbf{dg_{2,2}}$, $\mathbf{dg_{3,1}}$, $\mathbf{dg_{3,2}}$, $\mathbf{dg_{4,1}}$, $\mathbf{dg_{4,2}}$, $\mathbf{dg_{5,1}}$, $\mathbf{dg_{5,2}}$ show the lengths between each point of each panel's glazing in the –Y direction, which range from 0.10 to 0.60 meters. Besides, $\mathbf{ra_1}$, $\mathbf{ra_2}$, $\mathbf{ra_3}$, $\mathbf{ra_4}$, $\mathbf{ra_5}$ show the angle of rotation of each panel around the X axis, which varies between -45° and 45°. Moreover, $\mathbf{m_{1,1}}$, $\mathbf{m_{2,1}}$, $\mathbf{m_{3,1}}$, $\mathbf{m_{4,1}}$, $\mathbf{m_{5,1}}$ show how each point on each panel moves in the X direction, shifting between -2.50 meter and 1.00 meter, while $\mathbf{m_{1,2}}$, $\mathbf{m_{2,2}}$, $\mathbf{m_{3,2}}$, $\mathbf{m_{4,2}}$, $\mathbf{m_{5,2}}$ show the X-direction motions within each point around each panel, which vary between -1.00 meter and 2.50 meter.

Table 8 Design variables and explanations (by author).

Variable	Explanation	Range	Unit	Type
$\mathbf{dg_{1,1}}$	Distance from glazing of 1. point of 1. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{dg_{1,2}}$	Distance from glazing of 2. point of 1. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{ra_1}$	Rotation angle of 1. panel around X axis	[-45, 45]	degree	real
$\mathbf{m_{1,1}}$	Movement of 1. point of 1. panel in X direction	[-2.5, 1.0]	meter	real
$\mathbf{m_{1,2}}$	Movement of 2. point of 1. panel in X direction	[1.0, 2.5]	meter	real

Variable	Explanation	Range	Unit	Type
$\mathbf{dg_{2,1}}$	Distance from glazing of 1. point of 2. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{dg_{2,2}}$	Distance from glazing of 2. point of 2. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{ra_{2}}$	Rotation angle of 2. panel around X axis	[-45, 45]	degree	real
$\mathbf{m_{2,1}}$	Movement of 1. point of 2. panel in X direction	[-2.5, 1.0]	meter	real
$\mathbf{m_{2,2}}$	Movement of 2. point of 2. panel in X direction	[1.0, 2.5]	meter	real
$\mathbf{dg_{3,1}}$	Distance from glazing of 1. point of 3. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{dg_{3,2}}$	Distance from glazing of 2. point of 3. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{ra_{3}}$	Rotation angle of 3. panel around X axis	[-45, 45]	degree	real
$\mathbf{m_{3,1}}$	Movement of 1. point of 3. panel in X direction	[-2.5, 1.0]	meter	real
$\mathbf{m_{3,2}}$	Movement of 2. point of 3. panel in X direction	[1.0, 2.5]	meter	real
$\mathbf{dg_{4,1}}$	Distance from glazing of 1. point of 4. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{dg_{4,2}}$	Distance from glazing of 2. point of 4. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{ra_{4}}$	Rotation angle of 4. panel around X axis	[-45, 45]	degree	real

Variable	Explanation	Range	Unit	Type
$\mathbf{m_{4,1}}$	Movement of 1. point of 4. panel in X direction	[-2.5, 1.0]	meter	real
$\mathbf{m_{4,2}}$	Movement of 2. point of 4. panel in X direction	[1.0, 2.5]	meter	real
$\mathbf{dg_{5,1}}$	Distance from glazing of 1. point of 5. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{dg_{5,2}}$	Distance from glazing of 2. point of 5. panel in -Y direction	[0.1, 0.6]	meter	real
$\mathbf{ra_{5}}$	Rotation angle of 5. panel around X axis	[-45, 45]	degree	real
$\mathbf{m_{5,1}}$	Movement of 1. point of 5. panel in X direction	[-2.5, 1.0]	meter	real
$\mathbf{m_{5,2}}$	Movement of 2. point of 5. panel in X direction	[1.0, 2.5]	meter	real

In addition, I identify four key constraints that govern the connection between each panel's shape. There must be no geometrical junction between each panel solid region, which is the one under the other, based on the current connection. For example, if the first panel is on top and the second panel is underneath the first, the algorithms must avoid intersecting them from any solid location while attempting to determine the best rotation angle for each one of them. As a result, the constraint equations (20), (21) and (22) are defined as follows:

$$\mathrm{N}\ (\mathrm{A_i} \cap \mathrm{A_{i+1}}) = 0 \tag{20}$$

$$\mathrm{i} = 1, \dots, 4 \tag{21}$$

$$\mathrm{A} = 1, \dots, 5 \tag{22}$$

Based on the aforementioned formulas, A_i indicates the panel number, and I runs from 1 to 4, thus in our instance we have 5 amorphous panels incorporated into the south façade of the sample office building. To prevent geometrical junction, the intersecting set of one panel after another must be equal to 0.

5.3.2. Objective Functions

The particular weather information is collected from the EnergyPlus official website only for one year when merging climate data in simulation models. The energy and daylight simulation are conducted in a Mediterranean climatic zone that has long, hot, and dry summers. I utilize 38.4072222 latitude, which is located in Izmir, Turkey, in the Radiance daylight simulation and the EnergyPlus thermal simulation. Individual objective functions relating to energy and daylight are established in the design employing simulation approaches. They are the maximizing of the average of UDI values and the reduction of total energy consumption, respectively as $\max(UDI_{AVG})$, $\min(TEC)$.

The UDI is a daylight measure that considers the proportion of hours per year that lighting conditions are satisfactory. The permissible illuminance values lie within a specific interval, which is [100-2000] lux, to give proper illumination without considerable glare. I utilized Radiance program for the daylight simulation, which estimates UDI with illuminance values, and the UDI is computed as in (23) and (24):

$$\mathrm{UDI}\ (\mathrm{Pt_i}) = \frac{1}{n}\sum_{j=1}^{n} \mathrm{H}\left(\mathrm{L}(\mathrm{Pt_i}, j)\right) \mathrm{X}100 \tag{23}$$

The daylight simulation result is denoted by the letters L (a, b). i is the sample point, and j is the time in the findings (within a year). H(x) is a function that shows the value of luminous intensity. It produces one if the input value is within the defined boundaries, and zero alternatively.

$$\mathrm{H}(x) = \begin{Bmatrix} 1, \text{if } 100 \le x \le 2000 \\ 0, \quad\quad\quad\quad\quad\quad \text{o/w} \end{Bmatrix} \tag{24}$$

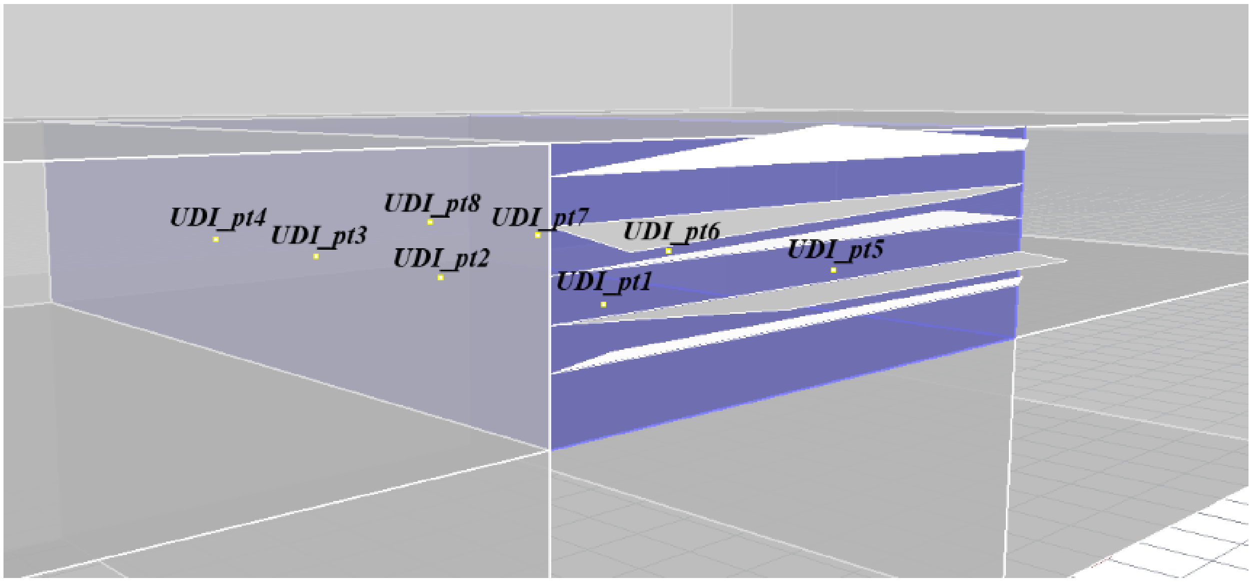


Figure 19 In the office room, the proposed shading device and UDI points (by author).

Surrogate modeling is used to enhance the daylight simulation speed by evaluating the regression of every UDI point as shown in Table 9. The daylight objective is calculated mathematically by averaging of the UDI values and using regression. I generate first samples for 1000 population size to forecast the UDI outcomes for each UDI point in the office space using daylight sensors (UDI points) as illustrated in Figure 20. The R-square numbers at the bottom of Table 9 correspond to the proportion of the daylight simulation outcomes that can be predicted. Consequently, throughout the optimization procedure, every generation for a population size of 100 requires less time than optimization without regression analysis. Equation (25) explains the average of 8 UDI values as follows:

$$\mathrm{UDI_{AVG}} = \mathrm{AVG}(\mathrm{UDI_{Pt_{1,\dots,8}}}) \tag{25}$$

Table 9 Table of regression coefficients for each UDI point (by author).

	UDIpt1	**UDIpt2**	**UDIpt3**	**UDIpt4**	**UDIpt5**	**UDIpt6**	**UDIpt7**	**UDIpt8**
constant	57.894	97.04	40.717	16.304	58.721	97.81	38.284	15.766
$\mathbf{dg_{1,1}}$	1.367	-2.627	-5.794	-2.563	5.344	-2.639	-6.681	-3.260
$\mathbf{dg_{1,2}}$	6.108	-2.822	-7.624	-3.913	2.182	-3.058	-5.714	-3.553
$\mathbf{ra_{1}}$	-0.04926	0.03404	0.14520	0.10194	-0.04814	0.03563	0.14047	0.10089
$\mathbf{m_{1,1}}$	-0.5799	0.333	0.650	0.2521	-0.0856	0.304	0.490	0.1959
$\mathbf{m_{1,2}}$	-0.0120	-0.026	-0.178	-0.0560	0.4861	-0.144	-0.3347	-0.1007
$\mathbf{dg_{2,1}}$	3.070	-3.086	-5.476	-2.932	7.660	-4.294	-6.716	-3.179
$\mathbf{dg_{2,2}}$	8.488	-4.266	-7.825	-4.365	2.378	-3.297	-5.486	-3.357
$\mathbf{ra_{2}}$	-0.06435	0.04699	0.12384	0.05404	-0.06325	0.04370	0.11894	0.05756
$\mathbf{m_{2,1}}$	-0.7063	0.392	0.402	0.0926	-0.0812	0.188	0.1649	0.0411
$\mathbf{m_{2,2}}$	0.0342	-0.013	-0.387	-0.3330	0.6165	-0.281	-0.4672	-0.3154
$\mathbf{dg_{3,1}}$	2.275	-2.624	-3.683	-2.436	7.574	-4.260	-4.462	-2.648
$\mathbf{dg_{3,2}}$	8.276	-5.386	-4.239	-2.046	2.404	-2.820	-3.144	-1.506
$\mathbf{ra_{3}}$	-0.07319	0.04708	0.08291	0.03700	-0.06888	0.04533	0.08171	0.03767
$\mathbf{m_{3,1}}$	-0.7114	0.382	0.275	0.0649	-0.0680	0.155	0.0286	0.0640
$\mathbf{m_{3,2}}$	-0.0904	-0.042	-0.174	-0.0283	0.6929	-0.333	-0.2674	-0.1335

$\mathbf{dg_{4,1}}$	2.370	-2.635	-3.404	-1.511	9.575	-3.591	-3.600	-2.167
$\mathbf{dg_{4,2}}$	10.417	-4.277	-3.472	-2.121	2.799	-3.261	-2.265	-2.022
$\mathbf{ra_{4}}$	-0.08870	0.04667	0.06556	0.02984	-0.08561	0.04270	0.06481	0.02915
$\mathbf{m_{4,1}}$	-0.7962	0.254	0.397	0.2311	-0.0632	0.078	0.1523	0.2641
$\mathbf{m_{4,2}}$	0.0948	0.055	-0.142	-0.0335	0.8087	-0.227	-0.1502	-0.0068
$\mathbf{dg_{5,1}}$	1.369	-1.333	-0.686	-0.795	4.804	-2.492	-0.616	-1.069
$\mathbf{dg_{5,2}}$	5.344	-1.810	-1.631	-0.763	1.663	-0.135	-0.196	-0.184
$\mathbf{ra_{5}}$	-0.08717	0.02753	0.04346	0.01500	-0.08417	0.03131	0.04381	0.01508
$\mathbf{m_{5,1}}$	-0.3994	0.063	0.113	0.0434	0.0384	0.104	0.0149	0.0414
$\mathbf{m_{5,2}}$	0.1018	-0.026	0.136	-0.0028	0.5297	-0.265	-0.0491	0.0212
Rsquare	88.35%	35.47%	79.26%	62.17%	88.18%	33.63%	79.64%	62.59%

To assess the variances and determine the best-fitting regression model, 1000 samples of each variable are created between the bounds listed in Table 9. For example, the equation explains how to calculate $\mathrm{UDI_{pt1}}$ (26).

$$\mathrm{UDI_{pt1}} = 57.594 + 1.367 * \mathrm{dg_{1,1}} + 6.108 * \mathrm{dg_{1,2}} - 0.04926 * \mathrm{ra_1} + 3.070 * \mathrm{dg_{2,1}} + 8.488 * \mathrm{dg_{2,2}} - 0.06435 * \mathrm{ra_2} + 2.275 * \mathrm{dg_{3,1}} + 8.276 * \mathrm{dg_{3,2}} - 0.07319 * \mathrm{ra_3} + 2.370 * \mathrm{dg_{4,1}} + 10.417 * \mathrm{dg_{4,2}} - 0.08870 * \mathrm{ra_4} + 1.369 * \mathrm{dg_{5,1}} + 5.344 * \mathrm{dg_{5,2}} - 0.08717 * \mathrm{ra_5} - 0.5799 * \mathrm{m_{1,1}} - 0.0120 * \mathrm{m_{1,2}} - 0.7063 * \mathrm{m_{2,1}} + 0.0342 * \mathrm{m_{2,2}} - 0.7114 * \mathrm{m_{3,1}} - 0.0904 * \mathrm{m_{3,2}} - 0.7962 * \mathrm{m_{4,1}} + 0.0948 * \mathrm{m_{4,2}} - 0.3994 * \mathrm{m_{5,1}} + 0.1018 * \mathrm{m_{5,2}} \qquad (26)$$

Table 10 The regression model's summary (by author).

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.538[a]	.289	.288	2.26904	
2	.667[b]	.445	.444	2.00484	
3	.705[c]	.498	.496	1.90904	
4	.717[d]	.514	.512	1.87885	
5	.727[e]	.528	.526	1.85225	
6	.736[f]	.542	.539	1.82646	
7	.742[g]	.551	.548	1.80912	
8	.745[h]	.556	.552	1.80033	
9	.749[i]	.561	.557	1.79075	
10	.751[j]	.564	.560	1.78403	
11	.753[k]	.568	.563	1.77833	1.838
a. Predictors: (Constant), ra1					
b. Predictors: (Constant), ra1, ra2					
c. Predictors: (Constant), ra1, ra2, ra3					
d. Predictors: (Constant), ra1, ra2, ra3, dg22					
e. Predictors: (Constant), ra1, ra2, ra3, dg22, ra4					
f. Predictors: (Constant), ra1, ra2, ra3, dg22, ra4, dg12					
g. Predictors: (Constant), ra1, ra2, ra3, dg22, ra4, dg12, dg21					
h. Predictors: (Constant), ra1, ra2, ra3, dg22, ra4, dg12, dg21, m11					
i. Predictors: (Constant), ra1, ra2, ra3, dg22, ra4, dg12, dg21, m11, dg31					
j. Predictors: (Constant), ra1, ra2, ra3, dg22, ra4, dg12, dg21, m11, dg31, m22					
k. Predictors: (Constant), ra1, ra2, ra3, dg22, ra4, dg12, dg21, m11, dg31, m22, dg32					
l. Dependent Variable: UDIaverage					

Table 10 provides an overview of the multivariate regression, including R, R square, modified R square values, as well as standard errors. I utilized the stepwise variable selection technique, which would be a stochastic approach of fitting regression models in the identification of predictors.

Depending on a pre-specified metric, a variable is considered for addition to or deletion from the collection of independent variables at each step. The R square discrepancy between Tables 8 and 9 is also related to the UDI objective's demonstration method. Because the UDI daylighting indicator is displayed in this manner, I give the R square values of each UDI point in such a proportion in Table 9. Table 10 shows that the values of R, R square, and adjusted R square increase from top to bottom. The adjusted R square values, on the other hand, are somewhat smaller than R square values that is a positive thing because the adjusted R square values are the ones that accurately represent the percentages. Standard errors are going down, and they're all good. In the regression model, I utilize the Durbin Watson method. It's a sort of statistics test for residual autocorrelation. It is reasonable and makes more sense if the numbers are between 1.5 and 2.5. In the model, it is 1.838. The adjusted R square values are essentially a variant of the R square values that have been calculated on the basis of predictors in the statistical model. Only if the additional term enhances the model more than is predicted by coincidence does the adjusted R-square value rise. When a predictor improves the model by less than what would be anticipated by coincidence, the adjusted R-square value drops. Therefore, the adjusted R square value evaluates the descriptive power of regression models made up of different predictive values.

The R square values of 11 predictors in the statistical model are greater than the corrected R square values. R Square is a basic matrix that explains the amount of variation described by the statistical model. If we keep having extra variables, the R square value constantly rises, regardless of the importance of the variables. Adjusted R square, however, determines R square using just the significant variables in the model. As a result, when doing a multivariate linear regression, it is preferable to use modified R square values rather than R square values. The equation for calculating the adjusted R square value is as follows (27):

$$R_{adj}^2 = 1 - [\frac{(1-R^2)(N-1)}{N-K-1}] \qquad (27)$$

where n is the number of independent regressors and k is the number of points in the data sample

The surrogate model that we built for quicker daylight simulation is, however, still unclear. The reason for this is that I only made 1000 samples for one generation; if I had taken more than one generation, for example, I may have gotten greater percentages of Rsquare values in Table 8. Furthermore, because one generation of 1000 samples took too long to create, I only used one generation for this investigation. Radiance parameters employed in the daylight simulation model are another cause for the lower UDI % for UDIpt2 and UDIpt6. The energy simulation model, on the other hand, determines overall energy consumption by combining heating and cooling energy use. The overall energy consumption is calculated using EnergyPlus (*EnergyPlus*, 2021) in the simulation software. The second goal, as described in (28), (29) and (30), is to reduce overall energy use to the lowest possible level.

$$\mathrm{TEC} = \mathrm{EC_{cooling}} + \mathrm{EC_{heating}} \tag{28}$$

$$\mathrm{EC_{cooling}} = \sum_{n=1}^{12} \mathrm{EC_{cooling_n}} \tag{29}$$

$$\mathrm{EC_{heating}} = \sum_{n=1}^{12} \mathrm{EC_{heating_n}} \tag{30}$$

where n is the number of computed months in a year.

Because the climatic zone is hot and dry, I combine the heating and cooling energy consumptions ($\mathrm{EC_{heating}}$ and $\mathrm{EC_{cooling}}$) in the energy simulation model. In the same time step, EnergyPlus calculates heat balance and load, as well as system and plant calculations. Its framework is user-friendly and adaptable, allowing users to add additional simulation modules.

6. Implementation of the Proposed Framework

6.1. Multi-Objective Evolutionary Algorithms

Numerous researches on multi-objective evolutionary computing have been published in the literature so far. Among all algorithms, evolutionary algorithms are the most widely used, having been applied to a wide range of technical issues. NSGAII (Deb, 2002), and SPEA-2 (Zitzler et al., 2001) are two instances of these algorithms. However, in this research, I use jDE, JcGA-DE, MOHS, and NSGAII to solve the challenge of designing a smart floating city. These are improved versions of the initial algorithms.

6.1.1. jDE

In their pioneering work, Storn and Price (Storn, 1995) created DE. DE was then widely popularized, and it can now be seen in a variety of projects, including (Knowles & Corne, 1999), (Das et al., 2005).

The algorithm's progressive stages remain continuing in this dissertation, with NP individuals in the population holding a D-dimensional vector containing parameters. Depending upon the search intervals $[x_{ik}^{min}, x_{ik}^{max}]$, each vector is obtained in an arbitrary and consistent manner, as shown in equation (31):

$$x_{ik}^{0} = x_{ik}^{min} + \left(x_{ik}^{max} - x_{ik}^{min}\right) \times r \qquad (31)$$

where x_{ik}^{h} is i^{th} objected individual concerning k^{th}dimension in one generation h; and r is a arbitrarily nominated and uniform number between 0 and 1. Following that, the weight variances of the first two couples are added together to create a fifth individual, resulting in mutant individuals. As a result, individuals from the target population are utilized and selected at random.

$$v_{ik}^{h} = x_{ak}^{h-1} + F \times \left(x_{bk}^{h-1} - x_{ck}^{h-1} + x_{dk}^{h-1} - x_{ek}^{h-1}\right) \quad (32)$$

where a, b, c, d, e are five individuals that are elected from the population of target like $\left(a \neq b \neq c \neq d \neq e \neq i \in (1, .., NP)\right)$ and $k = 1, .., D$. $F > 0$ is a scale factor of mutation that is triggering the differentiating. As a result, recombining mutant individuals results in the target individuals, as shown in the continuity formula (33):

$$u_{ik}^{h} = \begin{cases} v_{ik}^{h} & if\ r_{ik}^{h} \leq CR\ or j = D_k \\ x_{ik}^{h-1} & otherwise \end{cases} \quad (33)$$

where D_k is a arbitrarily selected dimension $(k = 1,..,D)$. It indicates that in the target individual x_{ik}^{h-1}, at least one parameter from the trial individual u_{ik}^{h} will be different. CR is a user-defined crossover constant that ranges between 0 and 1, and r_{ik}^{h} is a random number between 0 and 1 with a uniform distribution. It is recommended that the production of trial individuals be done outside of the intervals. As a result, parameters that violate the search interval are limited to the following:

$$x_{ik}^{h} = x_{ik}^{min} + \left(x_{ik}^{max} - x_{ik}^{min}\right) \times r \quad (34)$$

The presence of the fittest is decided in the next generation, which includes both the trial and target individuals, as defined in the formula underneath (35):

$$x_{i}^{h} = \begin{cases} u_{i}^{h} & if\ f\left(u_{i}^{h}\right) \leq f\left(x_{i}^{h-1}\right) \\ x_{i}^{h-1} & otherwise \end{cases} \quad (35)$$

In the aforementioned DE method, I use a novel self-adapting parameter structure known as jDE. In the jDE structure, there are F_i and CR_i standards well-defined individually. Principally, they are allocated to $CR_i = 0.5$ and $F_i = 0.9$ and rationalized as in the subsequent calculations (36) and (37):

$$F_{i}^{h} = \begin{cases} F_a + r_1 . F_b & if\ r_2 < n_1 \\ F_{i}^{h-1} & otherwise \end{cases} \quad (36)$$

$$CR_{i}^{h} = \begin{cases} r_3 & if\ r_4 < n_2 \\ CR_{i}^{h-1} & otherwise \end{cases} \quad (37)$$

where $r_j \in \{1,2,3,4\}$ are integers between 0 and 1 that are uniform and chosen at random. n_1 and n_2 illustrate the many options for changing both CR and F. The parameters are specified as $n_1 = n_2 = 0.1$ and $F_a = 0.1$ and $F_b = 0.9$.

6.1.2. JcGA-DE

To correlate the findings with jDE, I utilize JcGA-DE, which stands for self-adaptive continuous genetic algorithm-differential evolution. The operator of binomial crossover is used in the JcGA method to discover offspring populations. Depending upon this, the individuals x_p and x_q who are known as members of the parent population, are chosen. Furthermore, the dimensions of the offspring are picked from the first two individuals with a perfect CR that directly corresponds to the probability of crossover.

Basically, the algorithm creates the offspring population, with a specific proportion of the offspring population going to a mutation operator at the discretion of the algorithm. Nevertheless, depending on the mutation operator, another procedure is proposed in the dissertation. The mutation operator of the DE (Das et al., 2016) method is used in another manner. To begin with, just three of them are picked from the parent's population in equation (38). The variance of two individuals is then multiplied by adding a uniformly and randomly determined value as "r" between 0 and 1 to another random individual. As a final step, the self-adaptive notion is used, as stated in equation (39) and (40) published by (Brest et al., 2006).

$$o_i^{j,t+1} = x_p^{j,t} + r \times \left(x_q^{j,t} - x_r^{j,t}\right) \tag{38}$$

$$F_i^{t+1} = \begin{cases} F_{min} + R_1 . F_{max} & \text{if } R_2 < p_1 \\ F_i^t & otherwise \end{cases} \tag{39}$$

$$CR_i^{t+1} = \begin{cases} CR_{min} + R_1 . CR_{max} & \text{if } R_2 < p_1 \\ CR_i^t & otherwise \end{cases} \tag{40}$$

where $R_j \in \{1,2\}$ are integers in the range of 0 to 1 that have been chosen at random and uniformly. p_1 belongs to the possibility to change the CR_i values. $p_1 = 0.1$, $CR_{min} = 0.1$ and $CR_{max} = 0.9$ that are symbolized as limitations. Also, F_{min} is 0.01 and F_{max} is 0.05.

The goal of the dissertation is to compare jDE and JcGA-DE by comparing the results of both algorithms during the optimization stage. Despite the fact that these algorithms are commonly used in engineering and benchmarking issues, I utilize them to solve a real-parameter multi-objective smart floating city problem that has yet to be addressed in the literature (Kirimtat et al., 2015b), (Cubukcuoglu, Chatzikonstantinou, Tasgetiren, et al., 2016a). In addition, the design options for the proposed smart floating city are obtained using the Pareto graphs of the jDE and JcGA-DE algorithms, which are assessed by displaying the computational and algorithmic findings.

6.1.3. NSGAII

Multi-objective optimization entails considering all conflicting objectives and searching for a collection of acceptable solutions that fulfill various restrictions while harmonizing the objectives. This collection of solutions is referred to as the set of Pareto optimum solutions in such situations. (Deb et al., 2002). Three basic ideas are utilized to describe relationships between possible solutions to multi-objective minimization problems. It's worth noting that we have P objectives.

Dominance relation: A viable solution if the two requirements below are met, $\vec{x}$ dominates another viable solution, $\vec{y}$ (symbolized as $\vec{x} \succ \vec{y}$):

$$\forall p \in 1,..,P; f_p(\vec{x}\,) \leq f_p(\vec{y})$$

$$\exists p \in 1,..,P; f_p(\vec{x}) < f_p(\vec{y})$$

A viable solution $\vec{r}$ slightly outperforms another viable solution $\vec{x}$ (symbolized as $\vec{x} \succcurlyeq \vec{y}$) if:

$$\forall p \in 1,..,P; f_p(\vec{x}\,) \leq f_p(\mathrm{y})$$

Non-dominated set ($\boldsymbol{X}^*$): The non-dominated set of solutions (X^*) is a subset of a set of solutions (X) that are not dominated by any member of set X.

Pareto-optimal set: The Pareto-optimal set is the non-dominated (Pareto-optimal) solution set of the whole viable search space.

After the initial population is generated, each individual is given a fitness (or rank) equal to its nondomination (level 1 is the best level 2 is the next-best level, and so on). In particular, for unconstrained multi-objective optimization, the crowded-comparison operator ($\succ$) is created. It guides the algorithm's selection criteria at various stages. Each individual i in the population has a crowding distance rank (i_{dist}) as well as a nomination rank (i_{rank}). The crowded-comparison operator ($\succ$) is described as in the following equation:

$$if\ (i_{rank} < j_{rank})\ then\ i \succ j$$

$$or\ ((i_{rank} = j_{rank})\ and\ (i_{dist} > j_{dist})) \qquad (41)$$

6.1.4. MOHS

The HS algorithm is a meta-heuristic method that was created lately by (Geem et al., 2005) and (Geem et al., n.d.). The HS algorithm is inspired by the musical activity that is in search of the optimum condition of harmony. The creativity process of musicians with an optimization problem is discussed in a review article on HS (K. S. Lee & Geem, 2005). For example, each performer may be a design variable since the pitch range of the musical instrument equals the alphabet of the design variable. Furthermore, any musical harmony might relate to any solution at any given iteration, with listeners' aesthetic ability serving as the objective function. The HS method has the benefit of requiring less mathematical requirements than other algorithms and being easily adaptable to various optimization applications. The HS algorithm's parameters are HMCR, PAR, and BW.

The HS algorithm selects a individual an at random from the population P^t to create an offspring. Finally, through using parameters HMCR, PAR, and BW, I create a new individual as continues to follow:

Pseudo Code 4. Offspring generation by HS.

$\boldsymbol{Randomly\ select\ an\ individual\ a\ from\ population\ P^t}$

$\boldsymbol{Randomly\ generate\ three\ uniform\ random\ numbers, r_1, r_2, r_3}$

$\boldsymbol{if\ (r_1 < HMCR)\ \ then}$

$\boldsymbol{s_{new} = s_a\ where\ \ a \in (1, 2, \ldots, P^t)}$

$\boldsymbol{if\ (r_2 < PAR)\ \ then}$

$\boldsymbol{s_{new} = s_a \mp r_3 * BW}$

$\boldsymbol{endif}$

$\boldsymbol{else}$

$\boldsymbol{s_{new} = s_{min} + r_3 * (s_{max} - s_{min})}$

Where $\boldsymbol{HMCR = 0.95, PAR = 0.3\ and\ BW = 0.01}$

I produce a new offspring population Q^t by utilizing the jDE or HS offspring generation strategies. After that, I merge the two populations as $R^t = P^t \cup Q^t$.

For the following generation, a combined population is formed initially, similar to the NSGAII process as $R^t = P^t \cup Q^t$. The size of the combined population R^t has a size of $2NP$ now. All individuals' crowding distances is calculated. After that, the population R^t must be organized based on nondomination. It should be noted that both former and present members of the population will be included in R^t, later; preceding nondominated solutions will be in R^t. The best nondominated solutions will now be saved in the set after sorting as F_1. If F_1 is lower than NP, all nondominated solutions for the new or next population will be picked as P^{t+1}. The population's remaining members will be chosen from successive nondominated fronts based on their rankings. As a result, individuals from the set F_2 are chosen first, followed by those from the set F_3, and so on. This process is continued until the population reaches NP in size. If indeed the count of the final nondominated individual l exceeds NP, the set F_l will be sorted in decreasing order using the crowded-comparison operator, and the least crowded individuals will be chosen to finish the next population. The modified size NP population is now employed for another iteration till a termination criterion is met. Ultimately, the following is Pseudo Codes of the jDE and MOHS algorithms:

Pseudo Code 5. The summary of the jDE and MOHS algorithms.

$Set\ t = 0\ and\ create\ a\ random\ parent\ population\ P^t\ with\ size\ of\ NP$

$Use\ JDE\ or\ HS\ operators, explained\ above, on\ P^t\ to\ obtain\ Q^t\ with\ size\ NP$

$If\ the\ termination\ criteria\ is\ satisfied, stop\ and\ return\ P^t.$

$Set\ R^t = P^t \cup Q^t\ to\ combine\ two\ populations$

$Perform\ a\ NDS\ procedure\ for\ R^t\ to\ set\ the\ nondominated\ fronts\ \ F_1, F_2, .., F_k.$

$For\ i = 1, .., k, repeat\ the\ following\ steps$:

$Calculate\ crowding\ distance\ for\ each\ solution\ in\ F_i.$

$Create\ P^{t+1}\ as\ follows$:

$if\ |P^{t+1}| + |F_i| \leq NP, then\ set\ P^{t+1} = P^{t+1} \cup F^t$

$if\ |P^{t+1}| + |F_i| > NP, then\ add\ the\ least\ crowded$

$NP - |P^{t+1}|\ solutions\ from\ F_i\ to\ P^{t+1}.$

$Apply\ JDE\ or\ HS\ operators\ to\ P^{t+1}\ and\ obtain\ new\ offspring\ population\ Q^{t+1}$

$Set\ t = t + 1\ and\ if\ t < SC, go\ to\ Step\ 3, else\ stop\ and\ report\ the\ Pareto\ front$

7. Results and Discussion

In this dissertation, four alternative evolutionary algorithms are given for application in the optimization phases of smart floating city design problems: jDE, JcGA-DE, NSGAII, and MOHS. Actually, by considering two competing objective functions, I'm attempting to use four distinct multi-objective evolutionary algorithms with diverse mutation operators. As may be seen in the examples, there are numerous distinct uses of multi-objective evolutionary algorithms in architecture (Karaman et al., 2017), (Yufka et al., 2017), (Cubukcuoglu, Chatzikonstantinou, Ekici, et al., 2016).

In the continuation of this part, the Pareto front results of the 3 different case studies will be discussed. The results obtained from the Pareto fronts of 3 different case studies show the near optimal choices of each problem. According to Pareto-efficient frontiers in other words Pareto-optimal frontiers, there is no single solution, which representsthe best case. All the solutions are near optimal and could be stated as optimal solutions according to user-preferences. The following three concepts are different Pareto front techniques used in the engineering problems:

- Given an initial situation, a Pareto improvement is a new situation where some agents will gain, and no agents will lose.
- A situation is called Pareto dominated if there exists a possible Pareto improvement.
- A situation is called Pareto optimal or Pareto efficient if no change could lead to improved satisfaction for some agent without some other agent losing or if there is no scope for further Pareto improvement.

Our solutions are the third one, which is Pareto optimal or Pareto efficient solutions.

7.1. Results of Case Study 1

When the 150 generations are completed in the first case study, the 250-population size diverge, and both Pareto graphs are depicted in Figures 21 and 22. In particular, Table 11 and Table 12 exhibit the solutions from the Pareto fronts, accordingly. As illustrated in Figure 23, these design solutions are represented by info graphics in four distinct hues. In the proposed smart floating city concept, each hue indicates a separate function as agricultural areas, residential areas, green areas and public areas.

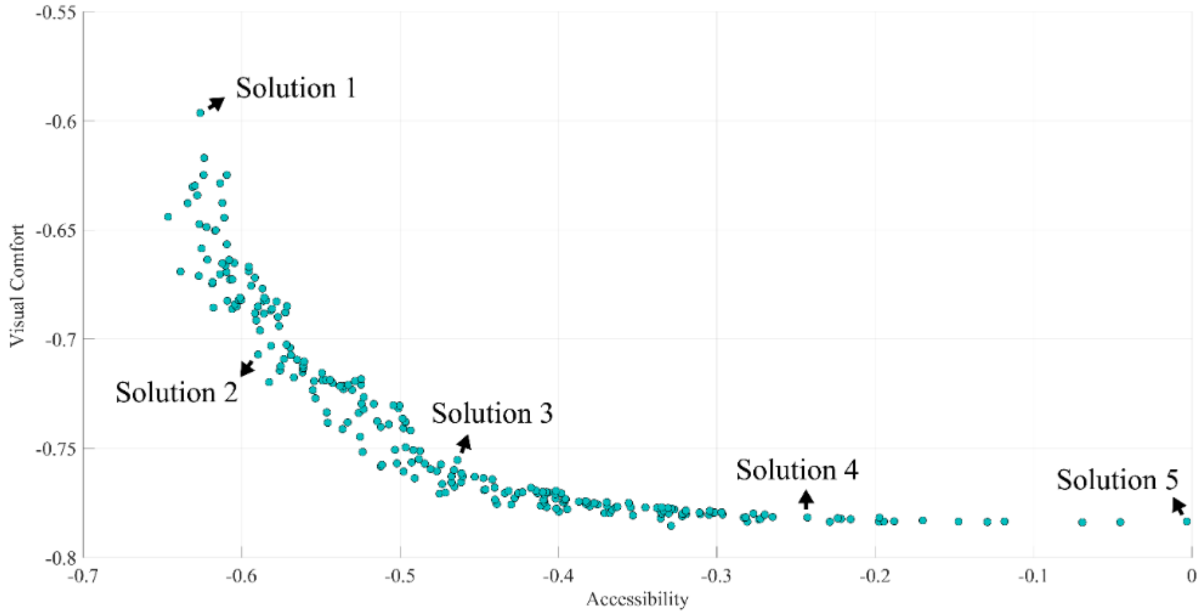


Figure 20 The jDE algorithm's optimization findings for visual comfort and accessibility (by author).

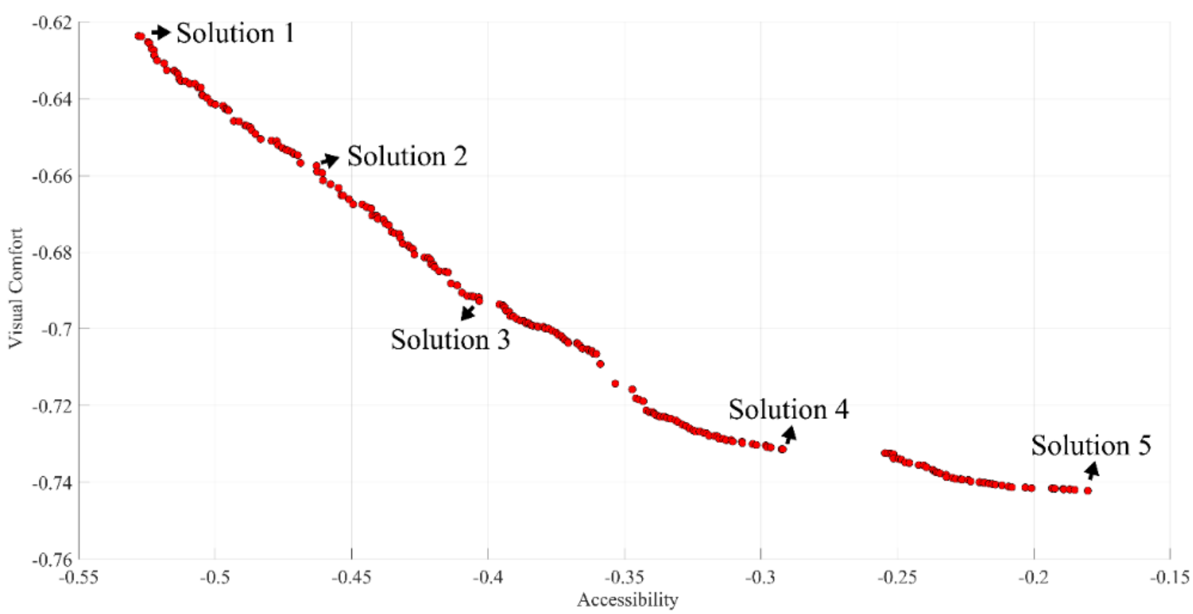


Figure 21 The JcGA-DE algorithm's optimization findings for visual comfort and accessibility (by author).

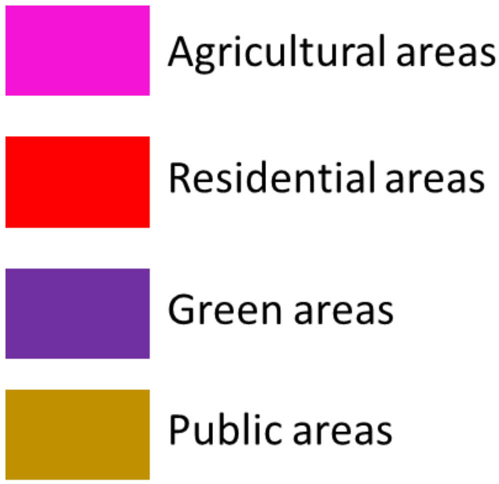


Figure 22 The utilized colorbars of the functions (by author).

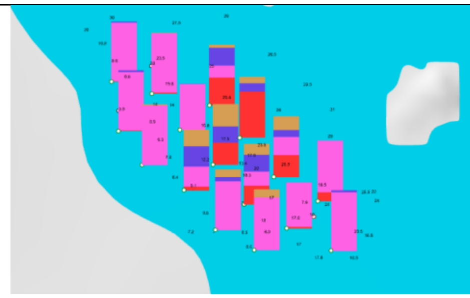
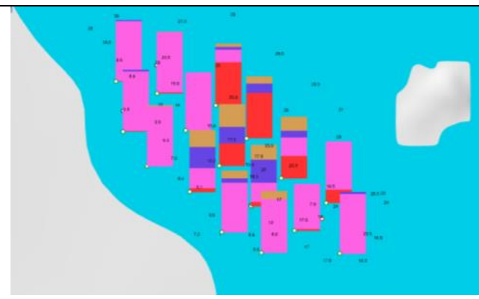
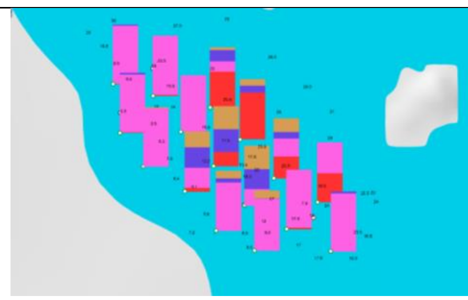
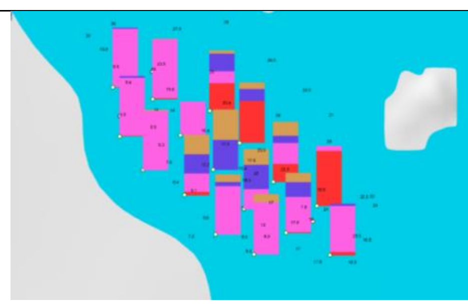
Table 11 The solutions derived from the Pareto Front of the jDE algorithm (by author).

Solution	**Solution in Image**
Solution 1 in jDE algorithm Accessibility: 59,2% Visual Comfort: 64,6%	
Solution 2 in jDE algorithm Accessibility: 48,7% Visual Comfort: 65,9%	
Solution 3 in jDE algorithm Accessibility: 41,2% Visual Comfort: 69,4%	

Solution 4 in jDE algorithm Accessibility: 25,3% Visual Comfort: 77,8%	
Solution 5 in jDE algorithm Accessibility: 0,7% Visual Comfort: 75,7%	

Variations in the info graphics can be observed very obviously according to the solutions derived from the Pareto front of jDE as shown in Figure 21. In addition, the color pink denotes agricultural areas, whilst the color red denotes residential areasIn the smart floating city concept, the other two hues, purple and yellow, represent green spaces and public areas, respectively. For example, in Solution 1, six clusters near the water contain four distinct services, indicating that accessibility inside the smart floating city is critical in this solution. When I analyze Solution 5, on the other hand, it is apparent that residential zones are quite near to the sea, since visual comfort is crucial in this case.

Table 12 The solutions derived from the Pareto Front of the JcGA-DE algorithm (by author).

Solution	**Solution in Image**
Solution 1 in JcGA-DE algorithm Accessibility: 53,2% Visual Comfort: 63,8%	
Solution 2 in JcGA-DE algorithm Accessibility: 46,2% Visual Comfort: 65,9%	
Solution 3 in JcGA-DE algorithm Accessibility: 41% Visual Comfort: 69,7%	
Solution 4 in JcGA-DE algorithm Accessibility: 28,7% Visual Comfort: 73,1%	
Solution 5 in JcGA-DE algorithm Accessibility: 18,2% Visual Comfort: 75,7%	

I show the findings of two alternative evolutionary algorithms, namely jDE and JcGA-DE, achieved during the optimization phase of the proposed smart floating city design problem in this first case study. However, in terms of the provided problem formulation, which is specified in the algorithmic modeling context, two conflicting objective functions are attempting to be maximized. Essentially, I'm attempting to integrate real-parameter multi-objective optimization methods with the design of smart floating cities by balancing two conflicting objective functions: visual comfort of the dwellings on the floating structures as well as accessibility between the proposed settlement's nodes. There exist four different functions in the projected smart floating city design problem: residential, public, green, and agricultural areas. In regards of the objective functions, I'm attempting to find a suitable mix of these functions in each cluster. Finally, a satisfactory percentage is acquired for each function in each cluster.

7.2. Results of Case Study 2

For the second case study, I visualize the findings with various rendering pictures and pick 7 distinct design options from the Pareto front of jDE, MOHS, and NSGAII algorithms. Each image depicts the feasible solution derived from the Pareto fronts depicted in Figure 24. Many design options for two opposing objective functions are presented in these various sea-use combinations.

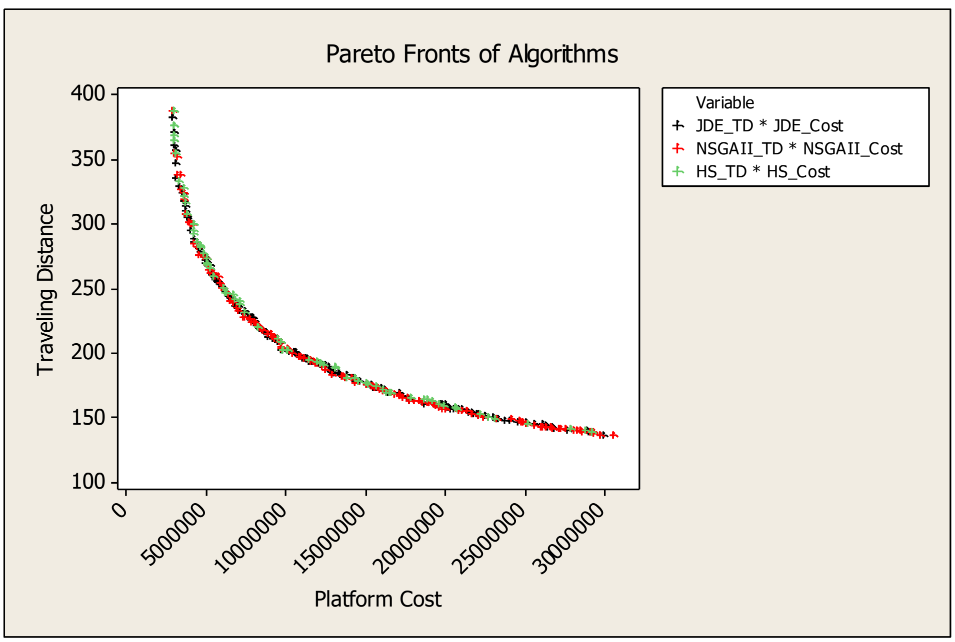
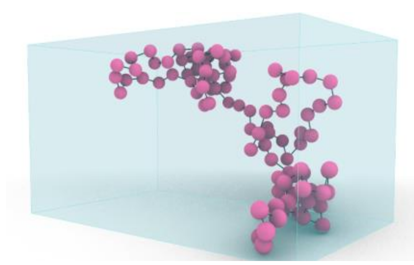
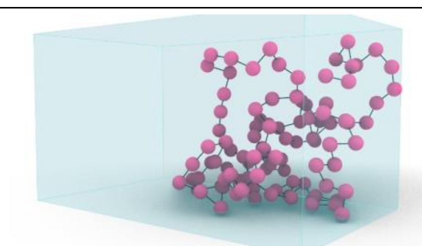
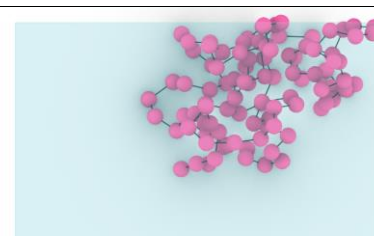


Figure 23 The optimization results of jDE, MOHS and NSGAII algorithms for “platform cost” and “travelling distance” (by author).

Table 13, Table 14, and Table 15 illustrate the design choices for the second case study. They're all derived from the Pareto front of both the jDE and MOHS algorithms, as well as the NSGAII algorithm. I essentially aim to keep infrastructure costs down and travel distances between cities to a minimum. For example, the first solution, which is based on the jDE algorithm, has the shortest trip lengths but numerous nodes with lower cost-effectiveness, and the nodes are highly congested and near to one another. On the contrary, the last solution, which is part of the JcGA-DE algorithm, has the longest travel distance while also being the most cost-effective in terms of the number of nodes that are extremely far apart. Apparently, the reason for the distance between nodes is due to the efficient sea-use arrangement, and when this objective is met, the transportation network expands and the distances between nodes grow. In this circumstance, the options with a wider transportation network result in the longest travel lengths. Similar findings may be found with the MOHS and NSGAII algorithms.

Table 13 The solutions derived from the Pareto Front of the MOHS algorithm (by author).

Solution	**Perspective View**	**Top View**
Solution1 MOHS Traveling Distance: 139.5593-meter Cost: 29.162.475,10 EURO Number of nodes/ platforms: 940		
Solution2 MOHS Traveling Distance: 159.0486-meter Cost: 19.859.730,50 EURO Number of nodes/ platforms: 655		

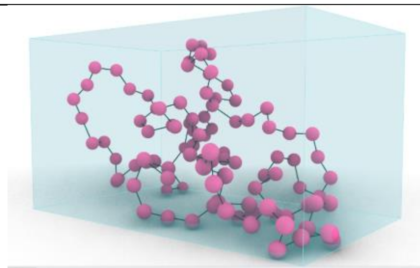
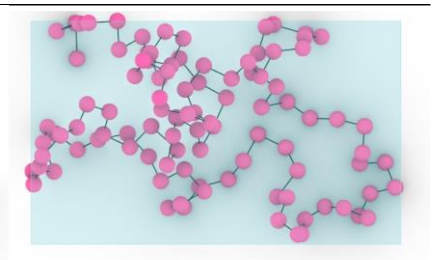
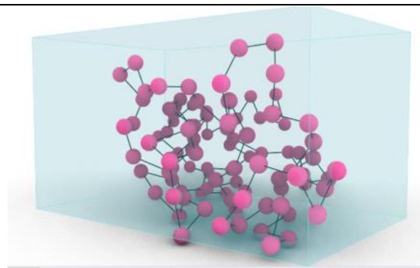
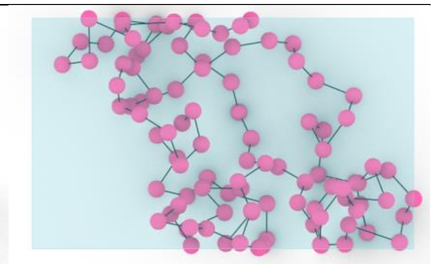
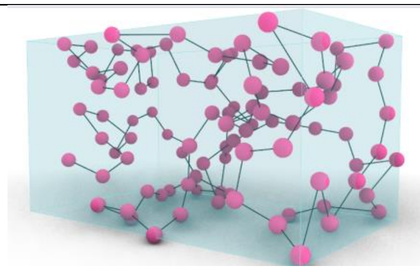
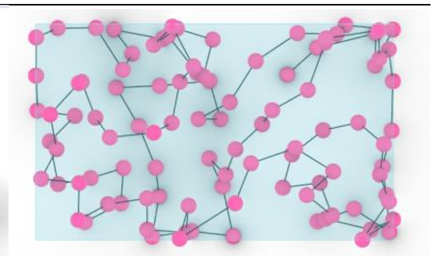
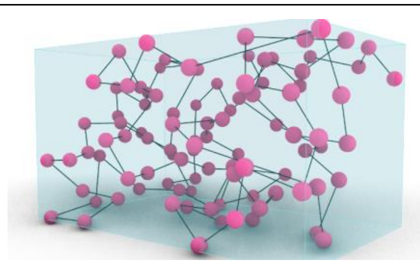
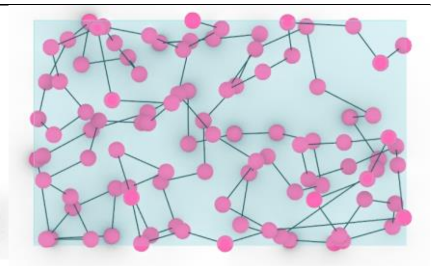
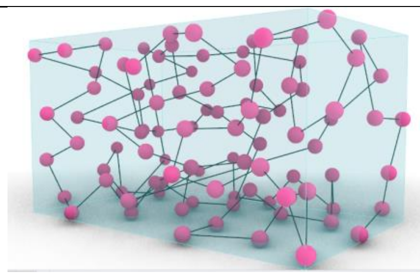
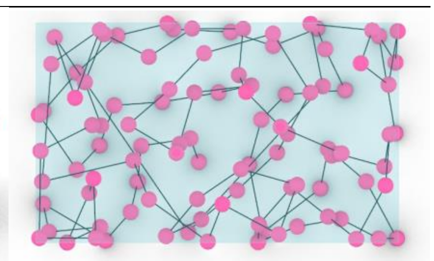
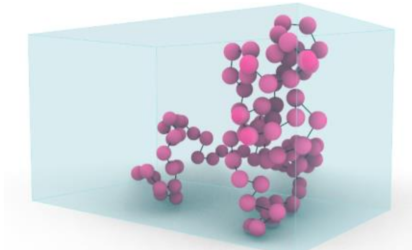
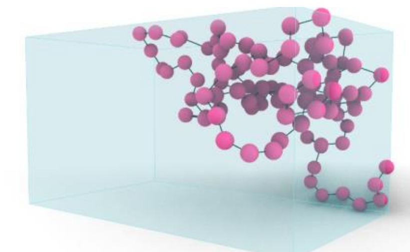
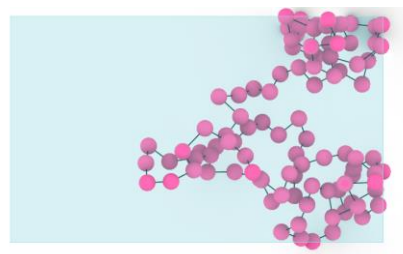
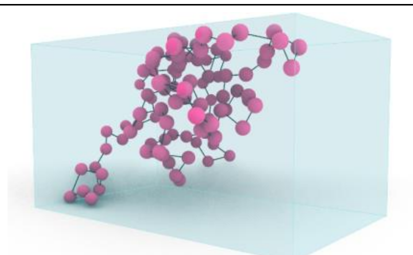
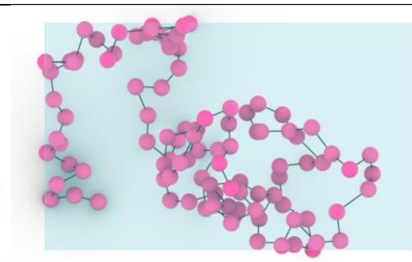
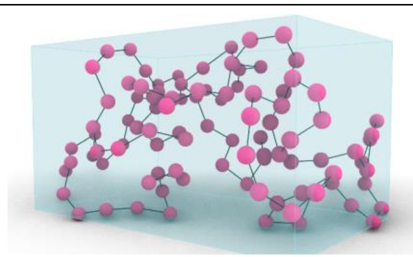
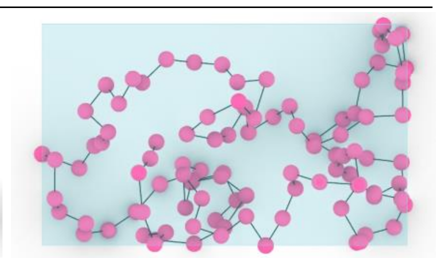
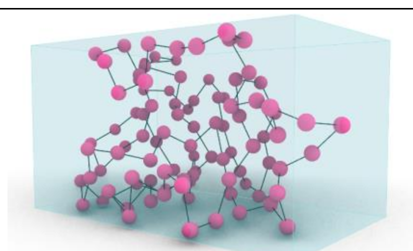
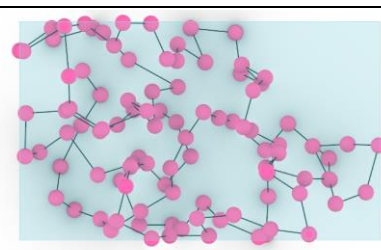
Solution3 MOHS Traveling Distance: 178.2974-meter Cost: 14.489.543,48 EURO Number of nodes/ platforms: 479		
Solution4 MOHS Traveling Distance: 219.9590-meter Cost: 8.268.941,20 EURO Number of nodes/ platforms: 273		
Solution5 MOHS Traveling Distance: 277.5772-meter Cost: 4.800.929,73 EURO Number of nodes/ platforms: 157		
Solution6 MOHS Traveling Distance: 327.8183-meter Cost: 3.550.533,77 EURO Number of nodes/ platforms: 118		
Solution7 MOHS Traveling Distance: 387.3974-meter Cost: 2.951.541,23 EURO Number of nodes/ platforms: 102		

Table 14 The solutions derived from the Pareto Front of the jDE algorithm (by author).

Solution	**Perspective View**	**Top View**
Solution1 JDE Traveling Distance: 136.4271-meter Cost: 29.957.359,09 EURO Number of nodes/ platforms: 986		
Solution2 JDE Traveling Distance: 151.5703-meter Cost: 22.515.329,02 EURO Number of nodes/ platforms: 743		
Solution3 JDE Traveling Distance: 176.4361-meter Cost: 15.021.682,11 EURO Number of nodes/ platforms: 486		
Solution4 JDE Traveling Distance: 208.6649-meter Cost: 9.656.749,61 EURO Number of nodes/ platforms: 321		
Solution5 JDE Traveling Distance: 255.3556-meter Cost: 5.744.081,50 EURO Number of nodes/ platforms: 191		

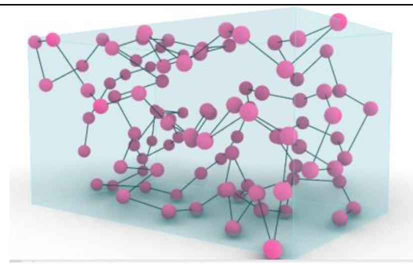
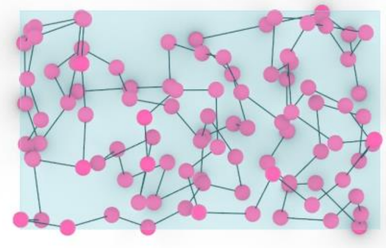
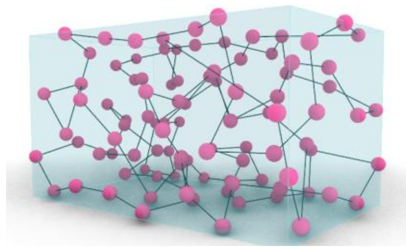
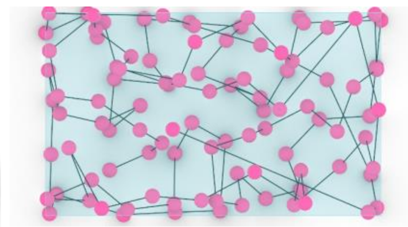
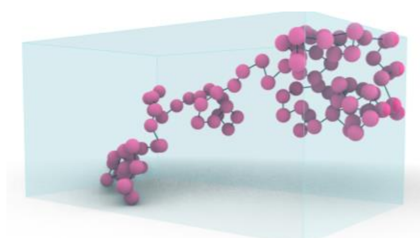
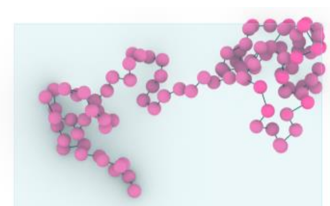
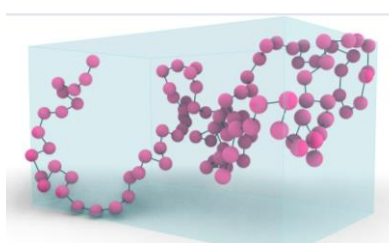
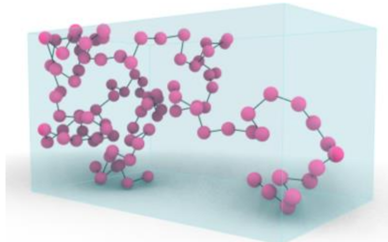
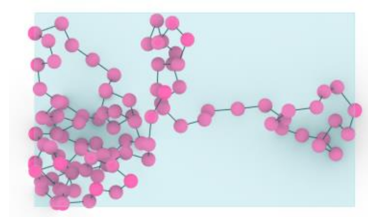
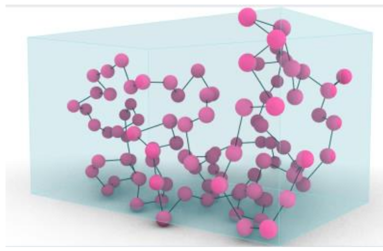
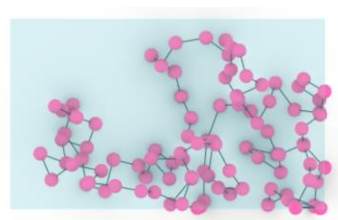
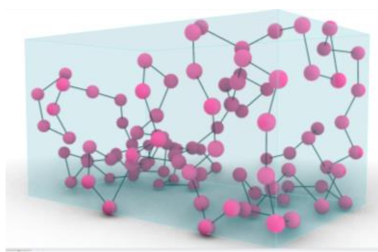
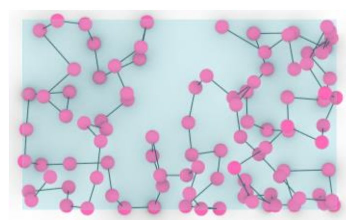
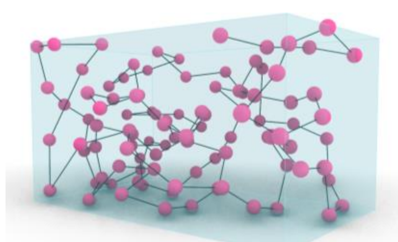
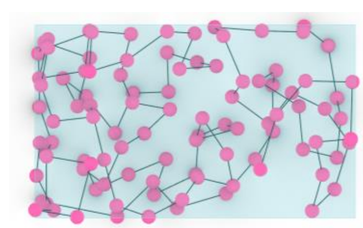
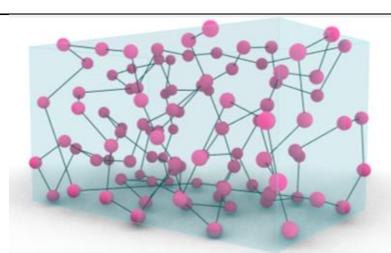
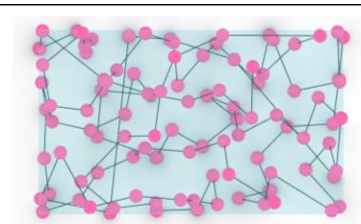
Solution6 JDE Traveling Distance: 309.6052-meter Cost: 3.717.357,51 EURO Number of nodes/ platforms: 122		
Solution7 JDE Traveling Distance: 382.6221-meter Cost: 2.899.091,72 EURO Number of nodes/ platforms: 100		

Table 15 The solutions derived from the Pareto Front of the NSGAII algorithm (by author).

Solution	**Perspective View**	**Top View**
Solution1 NSGAII Traveling Distance: 136.7146-meter Cost: 30.543.630,43 EURO Number of nodes/ platforms: 994		
Solution2 NSGAII Traveling Distance: 148.9406-meter Cost: 23.213.255,15 EURO Number of nodes/ platforms: 754		

Solution3 NSGAII Traveling Distance: 176.2430-meter Cost: 15.075.365,62 EURO Number of nodes/ platforms: 494		
Solution4 NSGAII Traveling Distance: 204.0246-meter Cost: 9.695.719,71 EURO Number of nodes/ platforms: 322		
Solution5 NSGAII Traveling Distance: 254.8236-meter Cost: 5.812.596,86 EURO Number of nodes/ platforms: 189		
Solution6 NSGAII Traveling Distance: 299.4214-meter Cost: 4.045.513,47 EURO Number of nodes/ platforms: 131		
Solution7 NSGAII Traveling Distance: 387.0978-meter Cost: 2.899.091,72 EURO Number of nodes/ platforms: 100		

7.3. Results of Case Study 3

Figure 25 compares and illustrates the Pareto graphs of NSGAII and JcGA-DE in this optimization problem. Between the bottom and top bounds of the Pareto fronts, possible solutions for each algorithm are chosen.

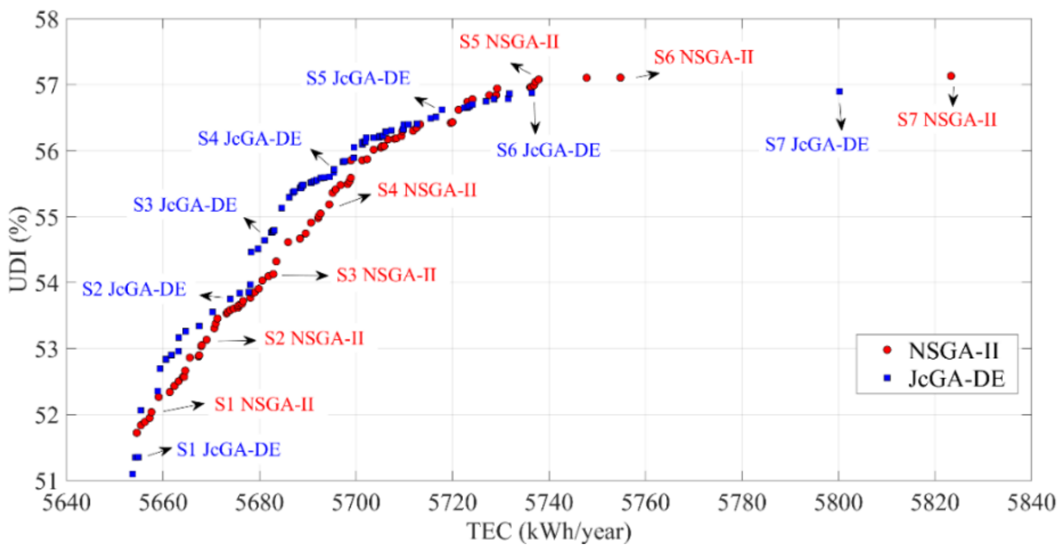
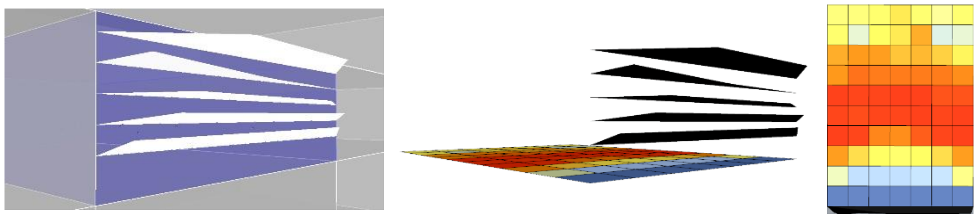
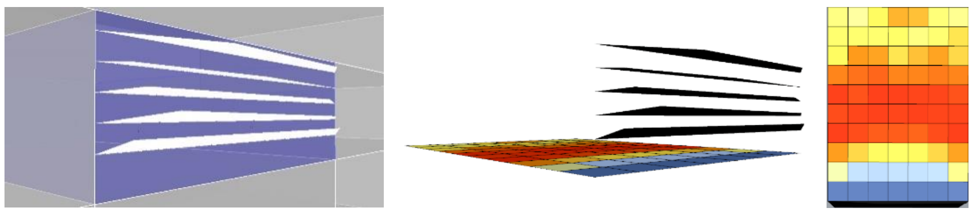
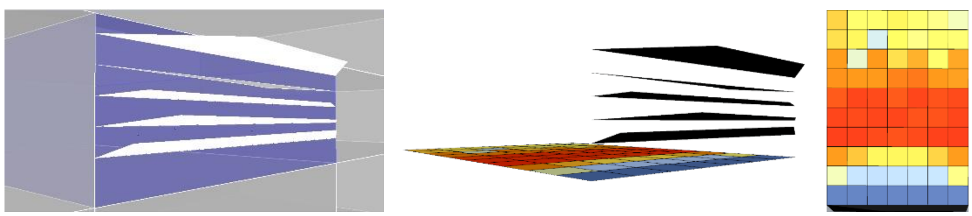
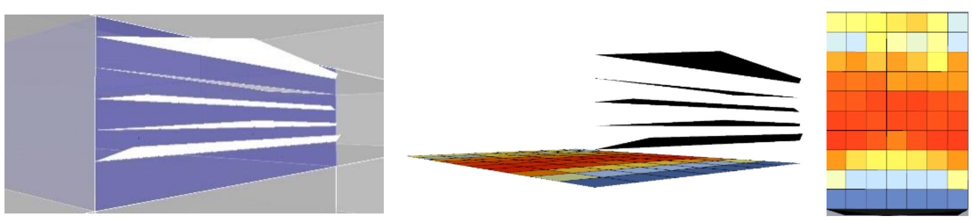
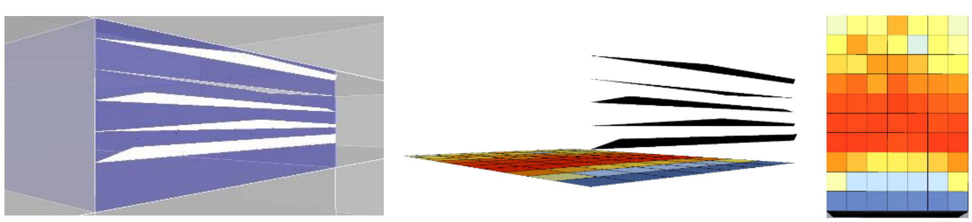
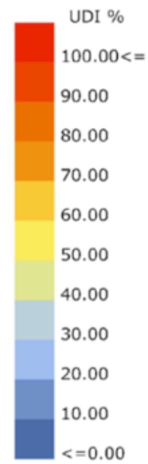


Figure 24 The optimization results of NSGAII and JcGA-DE algorithms for UDI and TEC (by author).

Table 16 and Table 17 show the alternatives highlighted in the Pareto rank of two methods for the third case study. Following the solutions column, the first column displays the panel geometries incorporated into the office room's south facade. The panel geometries with daylight levels distributed on the office floor are shown in the second column, while the top view of the office room with daylight availability on the floor is shown in the third column. UDI fluctuates between 0.00 percent and 100.00 percent on the top view. The blue grids are closer to 0.00 percent, whilst the red grids are closer to 100.00 percent. The yellow grids represent the average UDI value, which is around 50.00 percent. The UDI level in solution 1 for JcGA-DE, for example, is 51.34 percent. Table 16's top view with color rank in the same row shows that the average of the red color spectrum is greater than the blue color spectrum that sounds plausible. Furthermore, the UDI ratio for JcGA-DE is 56.89 percent, which has a larger average red color spectrum than solution 1, but the TEC value is greater in this case because the objective functions are incompatible. Table 18 depicts the similar condition for NSGAII.

Table 16 The solutions derived from the Pareto Front of the JcGA-DE algorithm (by author).

S1 JcGA-DE TEC: 5654.33 kWh/year UDI: 51.34%	
S2 JcGA-DE TEC: 5673.93 kWh/year UDI: 53.75%	
S3 JcGA-DE TEC: 5683.01 kWh/year UDI: 54.79%	
S4 JcGA-DE TEC: 5694.49 kWh/year UDI: 55.60%	
S5 JcGA-DE TEC: 5717.81 kWh/year UDI: 56.62%	

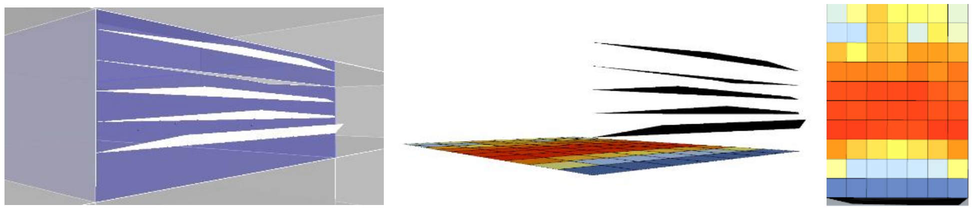


S6 JcGA-DE

TEC: 5731.83

kWh/year

UDI: 56.86%



S7 JcGA-DE

TEC: 5800.20

kWh/year

UDI: 56.89%

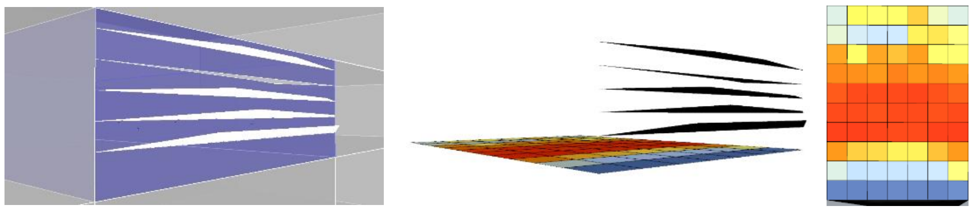


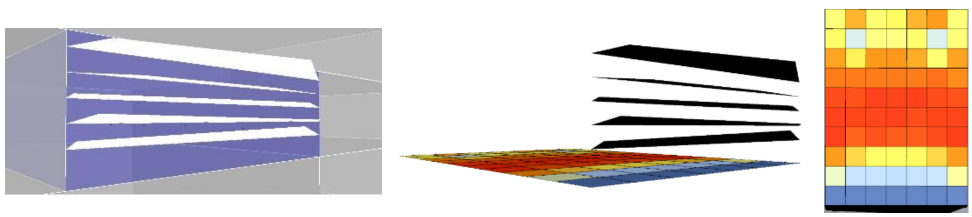
Table 17 The solutions derived from the Pareto Front of the NSGA-II algorithm (by author).

S1 NSGAII

TEC: 5657.60

kWh/year

UDI: 52.03%

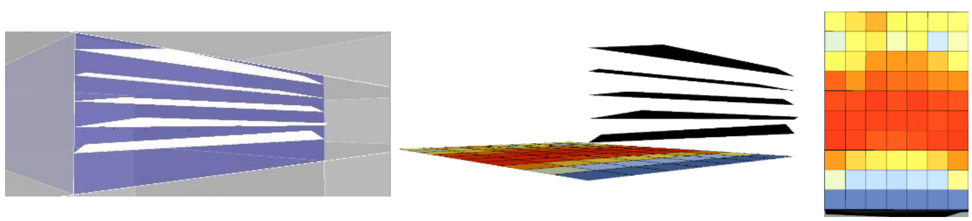


S2 NSGAII

TEC: 5669.03

kWh/year

UDI: 53.13%

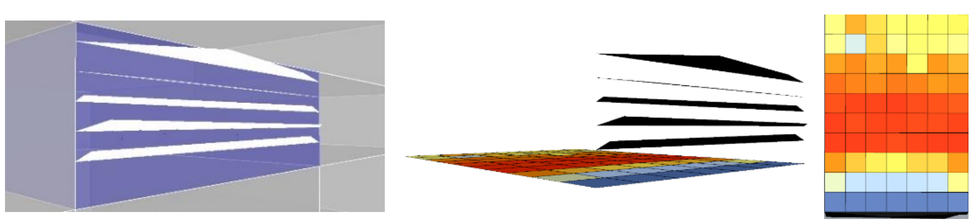


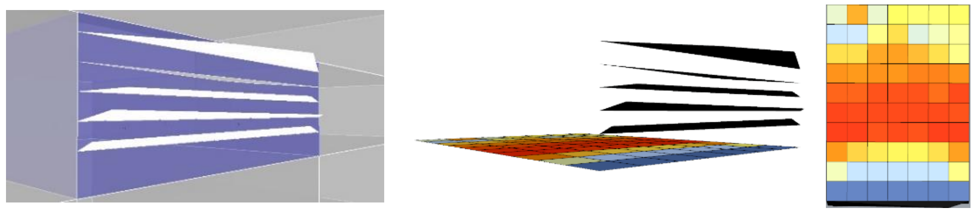
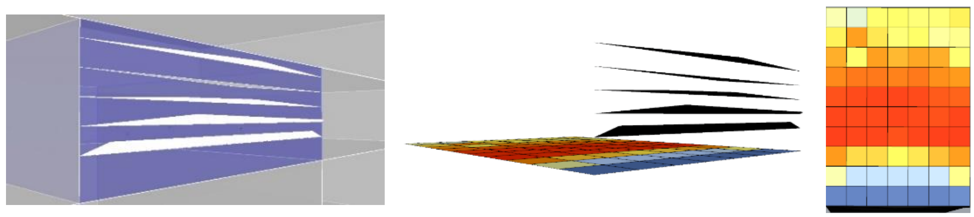
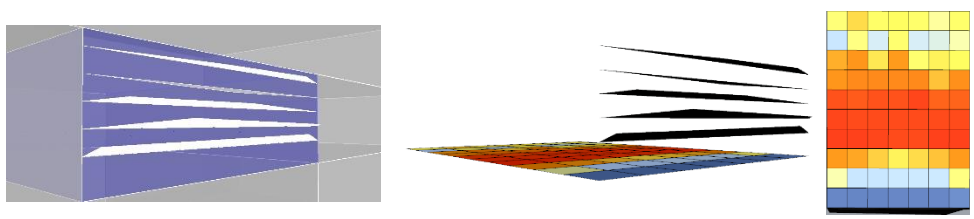
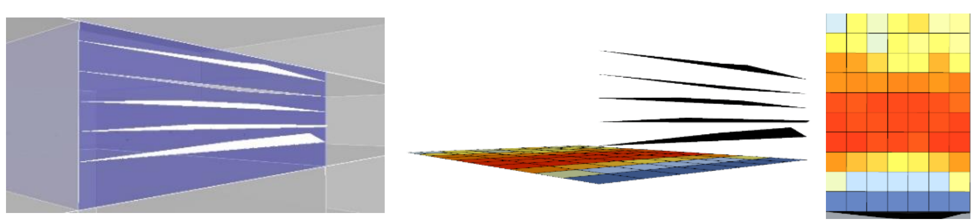
S3 NSGAII

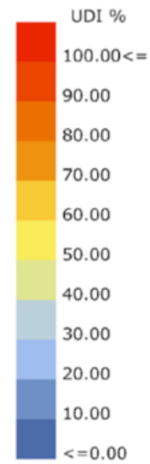
TEC: 5682.86

kWh/year

UDI: 54.12%



S4 NSGAII TEC: 5694.45 kWh/year UDI: 55.18%	
S5 NSGAII TEC: 5737.90 kWh/year UDI: 57.07%	
S6 NSGAII TEC: 5754.81 kWh/year UDI: 57.10%	
S7 NSGAII TEC: 5823.33 kWh/year UDI: 57.13%	



NSGAII obtains TEC values between 5657.60 kWh/year and 5823.33 kWh/year, whereas JcGA-DE reaches values between 5654.33 kWh/year and 5800.20 kWh/year, based on the current findings of the objective function of energy consumption in Table 16 and Table 17. NSGA-II provides UDI percentages between 52.03 and 57.13 percent for the second objective function, whereas JcGA-DE provides design options between 51.34 and 56.89 percent. Two evolutionary methods provide comparable answers for this building optimization problem depending on the intervals found. Because the objective functions are in conflict, design options with greater UDI percentages always result in higher TEC values than intended, and conversely. Additionally, while the transparent area of the office space is consistent for this design challenge, the size and rotation angle of every panel in the amorphous shading device impact the greater UDI values. Although the sizes of each panel have no influence on the TEC values, the sizes of the first panel on the top are the most significant choice factors for the designed shading device. All of the panels, on the other hand, enhance the UDI percentages by reflecting sunshine into the office space. Because the second and third panels lie in the center of the glazing portion, the rotation angles of these panels have a considerable impact on the UDI levels, according to the findings.

7.4. Comparison of the Results with the Existing Literature

Table 18 is the result of connecting the preceding floating city research with smart city concepts. It demonstrates the fundamental techniques used in floating city projects, and as a result, I discovered linkages between smart city themes. For instance, in the study of (Kirimtat & Krejcar, 2018), since both ideas deal with energy, the integration of the self-sufficiency method with renewable energy resources into floating cities might be connected to the smart energy topic. Also, another study by (Levi et al., 2019) carried out a novel strategy in terms of transportation efficiency, which may be linked to smart city transportation.

Table 18 The comparison of the results between this Ph.D. dissertation and the existing studies (by author).

Year	Approach	Smart City Theme	Author(s)
2013	Safety	Smart security	(Delta Sync, 2013)
2015	Walkability	Smart transportation	(Kirimtat et al., 2015a)
2019	Walkability	Smart transportation	(Kirimtat et al., 2019)
2018	Self-sufficiency	Smart energy	(Kirimtat & Krejcar, 2018)
2016	Accessibility	Smart transportation	(Cubukcuoglu, Chatzikonstantinou, Tasgetiren, et al., 2016b)
2020	Food and energy production	Smart energy	(Dal Bo Zanon et al., 2020)
2019	Land-use layout and transportation network	Smart environment, smart transportation	(Levi et al., 2019)
2019	Dwelling feasibility and occupant comfort	Smart building, smart people	(G. Wang et al., 2019)
2021	Visual comfort, accesibility, cost-efficiency, travelling distance, energy, daylight	Smart city, smart building	This Ph.D. dissertation

Cities beneath sea level (such as most cities in the Netherlands) are facing a big issue as sea levels rise nearly everyday, and they are attempting to find an alternate way to combat the problem of oncoming sea currents (Kirimtat et al., 2015a). Caused by global warming, increasing sea levels, and land scarcity, floating cities or communities have developed as a unique concept. The notion might also be viewed as a means of bringing about social and political change (Kirimtat et al., 2015a). Oceans are not controlled by any authority, and everyone has the liberty to utilize them as different living areas. As a result, oceans are our final hope of surviving on our planet (Proetzel, 1983).

8. Fulfillment of the Goals of the Dissertation

In this Ph.D. dissertation, what I deal with is to firstly analyze the existing smart city themes and various concepts and secondly analyze the smart floating city design problem and its different applications. As I have already given the main goals with their sub-goals of this Ph.D. dissertation in Section 2, they are fulfilled in the following sections of this dissertation. They are briefly given as follows:

- **"The main goal of this PHD dissertation is to create a computational theoretical model for smart floating cities by incorporating multi-performance criterion into the design process.".** This goal is fulfilled in Section 5 and Section 6 respectively, as I propose a new design and framework in Section 5 and I give the implementations of this framework with the modified multi-objective optimization algorithms in Section 6. Different multi-objective optimization algorithms based on different search methodologies to effectively solve the smart floating city design problems are presented.
- **"The first sub-goal of this dissertation is to propose a new concept namely as Smart Floating Cities by combining two popular concepts smart city and floating city.".** This goal is fulfilled within the whole Ph.D. dissertation by proposing something novel notably "Multi-Objective Optimization for Smart Floating City".
- **"The second sub-goal of this dissertation is to develop a smart floating city design in three different case studies utilizing optimization techniques, simulation approaches and computation tasks.".**This goal is fulfilled in Section 4 with the detailed problem formulations and in Section 5 with the design of the proposed framework and in Section 6 with implementation of the proposed framework and in Section 7 with the results of the computational models.

- Additionally, I list the other fulfillments regarding this Ph.D. dissertation during the whole Ph.D. study as below:
  - The essential part of the literature survey of different smart city concepts and themes is prepared and presented.
  - The essential part of the literature survey of smart cities is prepared as a review paper and submitted to high IF Q1 journal namely as IEEE Access and it is published.

- A research paper on the implementation of multi-objective optimization in smart building design problem is accepted and published in Solar Energy Q2 journal.
- A research paper on the implementation of multi-objective optimization in smart floating city design problem is accepted and presented in IEEE ICIT 2020 conference.
- A research paper on the implementation of multi-objective optimization in smart floating city design problem is accepted and published in Building and Environment Q1 journal.

In this dissertation, I present jDE, JcGA-DE, MOHS and NSGAII algorithms by comparing the performances in the optimization processes of three different case studies. Despite the fact that these evolutionary methods are often used in benchmark and engineering problems, I apply them to a multi-objective optimization-based smart floating city design challenge that has not been addressed in the published studies.

9. Conclusions

Many scientists have given several concrete examples of a smart city from diverse views and perspectives. To increase the smartness of the urban environment, one definition (Harrison et al., 2010) emphasizes the necessity for a link between physical, social, business, and ICT infrastructure. According to another interpretation (S. Kondepudi, personal communication, 2014) a contemporary city should use ICT to improve inhabitants' quality of life and urban services. These two definitions show how a smart city integrates the urban environment and ICT technology to improve day-to-day city operations and their performance for citizens (Silva et al., 2018). As a consequence of ICT technologies and markets, various smart city concepts and topics (smart people, smart transportation, etc.) are required, which must primarily utilize data management technologies such as IoT, Big Data, and Cloud Computing to establish a deep connection between each component and layer of a city.

Designers, on the other hand, consider architectural design as a difficult problem to solve. When the scale and complexity of geometries increase, developing anything new has larger demands. As a result of these factors, identifying potential design solutions among all possibilities at the early stages of the design process is extremely challenging. One of the best examples of difficult design problems is smart city designs. Furthermore, the design of smart cities is typically a multi-objective, high-dimensional optimization problem. Therefore, in this dissertation, using optimization methodologies and simulation approaches, a research is carried out by constructing a smart floating city. A stochastic strategy based on multi-objective mixed methodology-based Pareto fronts is also discussed. In the smart floating city, I also develop novel algorithms for tackling the multi-objective travelling salesman problem.

By implementing optimization approaches to three separate case studies of smart floating city design, the results of four distinct evolutionary algorithms, mainly jDE, JcGA-DE, MOHS, and NSGAII, are shown. Nevertheless, there are additional goals for the remainder of the Ph.D. dissertation that are simply listed below as future projections:

- There is still a shortage of scientific publications on smart floating cities, which appear to be promising candidates for future smart cities, given current scientific advancements.

- The use of multiple data management technologies, such as IoT, Big Data, and Cloud Computing, as well as certain heuristic approaches, might be considered for the implementation of smart city main themes and methods for floating settlements.
- Additionally, considering that there are a few instances of the application of the optimization methods for the design of floating settlements, multi-objective real parameter optimization algorithms may be utilized for the theoretical design of smart floating cities.
- Given the tremendous potential for constructing smart floating communities, they have the potential to become the world's future smart cities.

Based on existing scientific findings, I believe that there is currently a shortage of scientific publications on smart floating cities that appear to be promising prospects for future smart cities. The use of diverse data management technologies, such as IoT, Big Data, and Cloud Computing, might be considered for the implementation of smart city core themes and techniques for floating settlements. Moreover, provided that there are a few instances of the application of this method for the design of floating settlements, multi-objective real parameter optimization techniques might be utilized for the conceptual design of smart floating cities. They have the potential to be the world's future smart cities, despite the substantial possibility of constructing smart floating villages. Finally, I want to create awareness within the scientific community about the present status of smart city ideas by disclosing significant future developments, such as floating cities that use IoT technology and apps for multi-objective optimization.

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Author's Published Works

Journal Publications Related to Dissertation Topic

[1] A. Kirimtat, O. Krejcar, B. Ekici, M.F. Tasgetiren, "Multi-objective energy and daylight optimization of amorphous shading devices in buildings," Solar Energy 185, 100-111, 2019, https://doi.org/10.1016/j.solener.2019.04.048. **(Impact Factor: 5.742, Q2, External Citations of the publication in WOS: 26, External Citations of the publication in Scopus: 34).**

[2] A. Kirimtat, O. Krejcar, A. Kertesz, M.F. Tasgetiren, "Future Trends and Current State of Smart City Concepts: A Survey," IEEE Access 8, 2020. **(Impact Factor: 3.367, Q2/Q2/Q2, External Citations of the publication in WOS: 12, External Citations of the publication in Scopus: 17).**

[3] A. Kirimtat, O. Krejcar, M.F. Tasgetiren, E. Herrera-Viedma, "Multi-performance based computational model for the cuboid open traveling salesman problem in a smart floating city," Building and Environment 196, 107721, 2021, https://doi.org/10.1016/j.buildenv.2021.107721. **(Impact Factor: 6.456, Q1/Q1/Q1).**

Other Journal Publications

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Projects

IT4Neuro(degeneration), 2019 - 2022. Main proposer: doc. Ing. Miroslav Lísa, Ph.D. (FS UHK), reg. no.: CZ.02.1.01/0.0/0.0/18_069/0010054,

- Member of working group – FIM UHK at 50% FTE.

Grant Agency of Excellence project - Smart Solutions for Ubiquitous Computing Environments, Faculty of Informatics and Management University of Hradec Kralove, 2018-2021.

- Member of the research team as a junior researcher.

Internal student research project SPEV - Smart Solutions for Ubiquitous Computing Environments, Faculty of Informatics and Management University of Hradec Kralove, 2018-2021.

- Member of the research team as a junior researcher.

Superdoctorate Projects

- Analyzing Several Perspectives of Smart City Concepts: Smart Floating Cities (SFC) – October, November, December 2019.
- A Self-Adaptive Continuous Genetic Algorithm-Differential Evolution for the Median Cycle Problem in the Smart Floating City – February, March, April 2020.
- A Multi-Objective Harmony Search Algorithm for the Location-Allocation Problems in the Smart Floating Settlement – June, July, August 2020.
- A Multi-Objective Harmony Search Algorithm for a Photovoltaic Integrated Shading Device (PVSD) Design - October, November, December 2020.
- Intelligent control and optimization of photovoltaic shading devices (PVSD) for building energy management – February, March, April 2021.
- Multi-objective and intelligent control of photovoltaic integrated shading devices in buildings – June, July, August 2021.