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A – Applied Sciences and Engineering

16th Digital Design In Architecture Symposium

Volume 23 - 16th DDAS (MSTAS) - Special Issue 2022

ESKİŞEHİR TECHNICAL UNIVERSITY JOURNAL OF SCIENCE AND TECHNOLOGY
A- Applied Sciences and Engineering

Eskişehir Teknik Üniversitesi Bilim ve Teknoloji Dergisi A – Uygulamalı Bilimler ve Mühendislik

Volume 23 - 16th DDAS (MSTAS) - Special Issue 2022

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16th DDAS (MSTAS) Special Issue

Every year, the Digital Design in Architecture Symposium, where architecture and technology is discussed in different aspects of technology, is increasingly developing and attracting attention as one of the most important activities in this field in Turkey. Especially rapid and effective changes in information technologies increase this interest.

Artificial intelligence, simulation, virtual and augmented reality, human-computer interaction, and robotics, which are among the topics of DDAS (MSTAS) 2022, which we organize sixteenth in Eskisehir, indicate a wide ecosystem where many other disciplines are taking part. We call this wide frame, which is the common denominator of these areas, as "Digital Ecosystems". Digital ecosystems offer brand-new development and expansion areas for architecture and design with potential for interdisciplinary studies. Ecosystems are the upper systems in which different scaled subsystems can be balanced in transition to create a whole. During a period of brand-new professions in which inter -field transitions increase, the changes in the way of handling architecture, which is one of the most ancient professions in the world, point to this transition. From this point of view, the main theme of the Digital Design in Architecture Symposium was determined as "Digital Ecosystems and Architecture"

In January 2022, 95 expanded summary from 34 different Universities were sent to the call and after the referee assessment, 50 papers were found to be in accordance with the presentation. According to their subjects, the papers, were presented in thirteen sessions, some of which were handled in parallel and were evaluated in an active discussion environment. The symposium also hosted four workshops and enabled the active participation of undergraduate and graduate students.

In this special issue some of the papers presented in MSTAS 2022 will be published.

Special Issue Editors

Mehmet Ali ALTIN & Mehmet İNCEOĞLU

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RESEARCH ARTICLE

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16th Digital Design In Architecture Symposium
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MEASURING THE EFFECTS OF A CARTOGRAPHY-BASED PLATFORM ON THE ONLINE DESIGN PROCESS

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ABSTRACT

As the use of online learning in architectural education has increased, the patterns of the past are now being discussed considering the current pandemic. It is crucial to evaluate the strategies developed in this crisis when the institutional infrastructure, educators, and students rapidly adapt to this context. The use of cartography-based platforms (CBP) as an architectural information communication technology (ICT) enabled tool for interaction, ideation, and evaluation is examined in this research along with its potential and limits. It aims to contribute to the existing hybrid learning ecosystem. Research methodology is developed within the framework of integration, experimentation, and measurement. CBP experiments were modularly integrated into design courses in 2021 and 2022, respectively, and were conducted with the participation of approximately 400 students. In the scope of the course, each student (individually or in groups) is expected to have a field analysis and design proposal for a public space. Measurements related to three main factors and correlations between interface effects on user experience are based on the process, output, and questionnaires. Findings reveal the potential of the CBP strategy, which is implemented practically, to turn crises into opportunities. Statistical results related to measured factors underscore significant effects. Discussions based on the two experiments intensify on systematization, interaction, transparency, and parametrization in the online design process. According to the first experiment's feedback, customization of the interface provides positive results based on an independent T-test. The limitations or changing priorities could be improved with the ongoing experimental applications. Other related studies also support the different variants and widespread impact of the strategy designed and evaluated here. The study shows potential for modular or holistic use in different contexts. As a result, the use of CBP contributes to an up-to-date discussion with its outputs based on empirical studies at a variety of scales.

Keywords: Design education, Public space, Architectural-ICT tools, Cartography-based platform, Collective Intelligence

1. INTRODUCTION

The August 2020 COVID-19 report states that more than 190 countries and 1.2 billion students (Figure 1) are taking a break from face-to-face education due to the pandemic (UNESCO, 2020). There are many theoretical and practical studies with interactive, distance, and online learning environments, approaches, and methods in the associated literature. The research examined the Distance Education Journal published its first issue in 1980, the EDUCAUSE Horizon reports, and the Distance Design Education blog based in the UK. Several topics should be highlighted here, including collaborative learning and interaction styles, interactive learning and mass online courses, and pandemic-era online education and assessment methods (2005-2021) [1–4]. On the other hand, in the Turkish Online Journal of Distance Education, the first issue of which was published in 2021, discussions are sprouting in the pandemic environment. In addition to its constraints and difficulties, the pandemic crisis has a significant impact on paradigm shifts (O'Reilly, 2020), pivot points for widespread transformations (Salmon, 2020), or a turning point for design studios (Brown, 2020) particularly in the field of education [5]. As Thomas L. Friedman points out in his article 'Come the Revolution' in the NY Times (2012), revolutionary breakthroughs happen when the possible meets the desperately necessary. The online learning ecosystem transforming architecture and design education offers an opportunity to question the impossible patterns of the recent past.

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(a) (b)

Figure 1. Face-to-face education status at the beginning of the epidemic (a); total quarantine time (b) (UNESCO, 2022)

Nigel Cross, who played a role in the development of the first distance education courses in design (Open University), is significant for the theoretical framework of the research, with his discussions on design methods and the scientification of design from the 1960s to the present [6]. Recent trends that promote debate about methods, online ecosystem actors and their outputs have supported the significance of the factors that the study measures and is related to, especially in the last two years. A study includes the delivery, interaction, and assessment (DIA) model [8] that defines the main challenges of online teaching. It is seen that pedagogical clusters and components are represented by a network of intertwined diagrammatic relationships, and the basic factors determined in the DIA model are represented in a central spiral relationship. Six pedagogical clusters analyze the potential contributions of a sensitive and resilient architectural education based on social constructivism theory; empathy, activism, inclusivity, collaboration, change, digital learning, and teaching modes are emphasized [7]. Therefore, besides the focused factors and their effects on the learning ecosystem, the (dialectical) relations between these components are also crucial. This allows for a separate and contextual analysis of each factor's effects on the linked statement or statements. The factors focused on in the study should be discussed along with their positive and negative effects on this axis.

Field trips, teamwork, jury and group interactions in architecture, particularly design studios, are included in the research's consideration of online and hybrid learning environments. The problem area is supported by preliminary pilot studies conducted as well as global-scale reports and academic research. For example, a series of experimental studies and surveys conducted in 3 groups ($n = 36$) in the 2020 Fall semester Introduction to Architectural Design (IAD) studio provide relevant statistics in this context. As one of the factors measured here, the level of interaction factor (LIF) shows the importance of developing strategies against pandemic conditions. Contrary to a high value of 6.36 (m) in-group LIF on the 7-point Likert scale, LIF has a low value of 3.75 with other IAD groups and 2.11 with upper-period AD groups (Figure 9). Therefore, the strategies and methods developed at this crucial time when educators, students, and the institutional infrastructure are rapidly adapting can be evaluated from this perspective. In particular, to increase the efficiency and resilience of the online process, the integration of DIA-like models, their experimental application, and the measurement of their effects are required. The ICT tools and methods used in this context vary depending on the requirements of the online process. Computer-aided design tools and computational design thinking developed within architectural ICT provide a wide literature in this context. Sarıyıldız and Veer identify the role of ICT in AD education related to different purposes like (1) information processing tool, (2) communication tool, (3) visualization tool, (4) knowledge integration tool, (5) decision support tool, and (6) design tool [9].

Beyond geographic and urban studies, collective cartography is utilized as one of these methodologies with digital and physical interfaces in participatory and collaborative design processes [10] and design education [11,12]. The use of a cartography-based platform (CBP) is investigated in this study to determine its effects, potential, and limitations on three crucial factors: interaction, idea generation, and evaluation. It is anticipated that the research will contribute to the existing hybrid learning ecosystem both academically and practically. The research designed in this direction can be structured into a triple structure:

I. In the methodology section, the integration of the use of the cartography-based platform into the online ecosystem, descriptive information about the implementation process, and the tools used are included.
II. The findings obtained following the research methodology are presented within the framework of the (sub) factors that are intended to be measured. In addition to the targeted variables, the effects of the interface customizations are statistically examined by comparing the results of experimental applications conducted in consecutive years
III. Finally, the results of the study are evaluated on the axis of experimental practice and other related preliminary or international studies. In addition, the potential and limitations of the ongoing work process are discussed in the future projection.

2. METHODOLOGY

By implementing CBP, the research methodology is developed within the context of evaluating the outcomes and addressing the primary challenges encountered during the required and unexpected shift to online education. The CBP developed within this scope is modularly integrated into the online ecosystem. Therefore, the platform has the opportunity to be used periodically at different stages during the course process.

The first experimental study was carried out as a part of the online Introductory Computer Sciences (ICS) course at Yıldız Technical University, Department of Architecture, in the spring term of 2021. For CBP, the open source Emapic application connected to the Geographic Information System-based Leaflet library is used. Two (mid-term and end-term) stages of the process in which students participate are comprised of a total of 220 to 230 students (5% reduction in attendance during the semester) from three groups. It focuses on the public spaces in the city where students live and where they take the course online. Each student is expected to analyze the public space and develop a solution-oriented/data-driven/parametric design proposal. In groups of two, the initial analytical phase is completed, and each student completes their design concepts. Students apply the digital design techniques and tools they have acquired in the course during this process. In 2022, the application was repeated within the scope of the same course with the privatization of the interface in line with the findings of the previous year. A total of 170-180 students from three groups participated. Apart from the interface and the participants, the study areas (scale) also differ between the two applications. While the public spaces determined by each student in the different cities they were in during the quarantine period covered a very large area for experiment 1 (E1), this scale was limited to the city of Istanbul, where the university is located, for experiment 2 (E2) repeated in hybrid education conditions.

By taking an approach similar to the DIA model, three main factors were determined in the preliminary studies. These can be listed as the lack of sharing, discussion, and idea generation environment (f1: ideation), limited interaction level between and within groups (f2: interaction), and online assessment problem (f3: assessment). As a result, there are CBP strategies centered on interaction, production, and evaluation, as well as strategies that are mass generated (and consumed) by students, to fill the void left by the pandemic crisis' constraints and uncertainty (Figure 2). In addition to examining the implementation process and outputs of the strategy developed to provide an interactive, sensitive, productive, efficient, and inclusive design process that is open access for all, the student experiences and critiques are utilized to analyze the strategies produced and their effects. In this direction, the effects of the platform on group interaction, idea generation, and evaluation are measured with student questionnaires. In order to scale these three determined factors and to create a reference for similar studies, the necessary expressions regarding the interface, strategies, and experiences are also included in the survey. The feedback obtained in line with these statements forms the basis of the improvements in the interface repeated as E2 after E1.

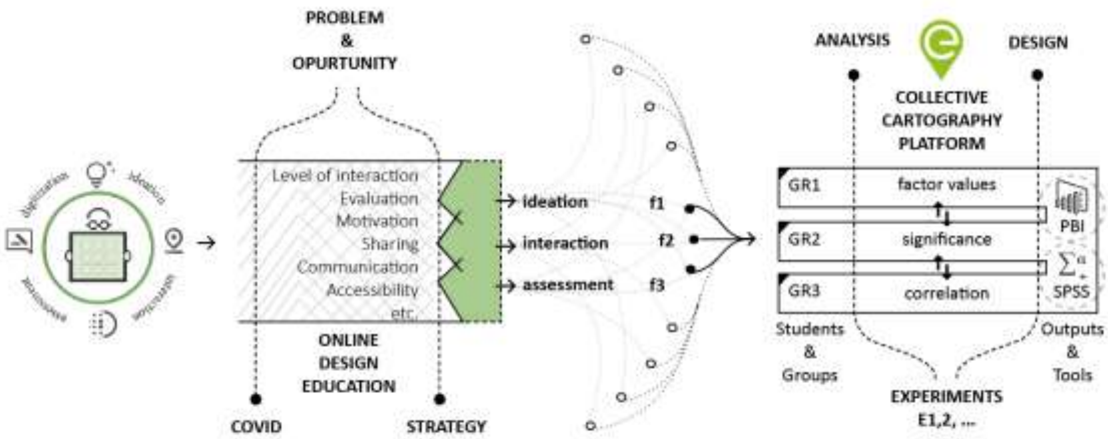


Figure 2. The strategy designed within the research methodology, the platform used, and the implementation phases (Author)

Students access the platform via the given link. First, the home page with the previous years and the option to upload active analyses and projects serves as a guide. Students have the choice of browsing through projects in the uploaded or past archives without actively uploading. Then, the student uploads her/his analysis or design proposal into the system within the framework of the structure created on the platform (Figure 3).

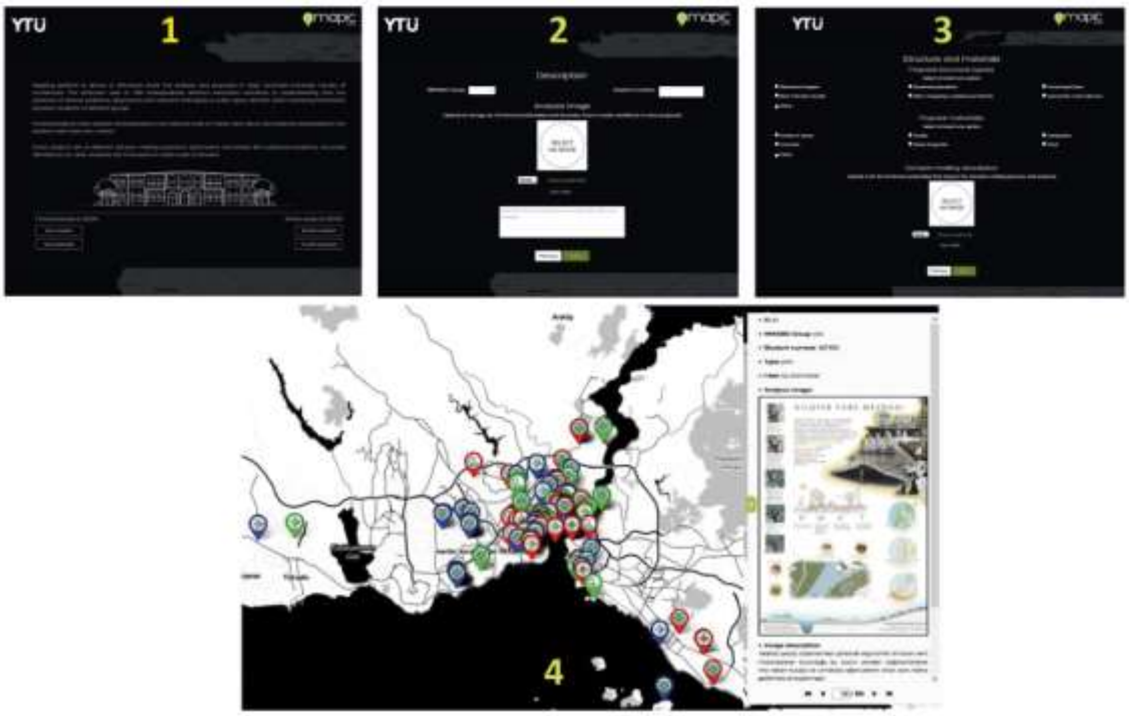


Figure 3. CBP (1) home page, (2) analysis, (3) design (4) data input and display of data uploaded to the platform (Author)

As part of the analysis phase, students upload the basic approaches covering three topics: the category of the study area, the type of problem(s) with the field, and the design proposal. Diagrams and drawings are used to assist with the studies carried out here. Between the analysis and design phases, the platform is accessible to all groups for approximately three months. Students and coordinators can examine the analysis data in the system, and it can be updated by uploading content in the specified process. Unlike E1, in which the platform is used for the first time, students in E2 can access their data entries from the previous year on the platform.

The second stage is aimed at constructing the evolution of design approaches in a parametric structure and questioning them together with other suggestions. This framework first encourages students to uncover the causalities regarding the decision mechanisms in their projects, and then to examine the problem-intervention or potential-intervention conjugates in different contexts in the platform contents. Therefore, beyond the digital tools used in design processes, students' problem-solving skills shape the structure of the platform in the context of parametric/computational design thinking. The content of the platform includes the student's design decisions, environmental (contextual) and design program parameters, structure type, and material choices. All content is additionally supported by animated visual context and approach steps.

Aside from parametrization, determining the concept for the intervention strategy is critical, especially since the project fields are public. The strategies take into account the PPS (Project for Public Space) public space design parameters and the triple (undo, redo, do not) approach of the n'UNDO organization. The contributions of the parametrically articulated design concepts (design phase) and the context-specific methodology specified in the analysis phase are questioned by self-evaluations. SPSS uses descriptive statistics and one-way ANOVA analysis for analyzing the scales and expressions in the survey conducted after the application. The independent T-test is used for the correlation between E1 and E2. Furthermore, the Power BI tool is used for online self-assessment analysis and data visualization.

While the Emapic resource for CBP was used in the beta version for the first phase applications (E1), some customizations were made in the interface and content in cooperation with the Coruña University Cartographic Engineering Laboratory for E2. Solutions have been developed in the redesigned interface to improve the following:

1. Demanding access to content from earlier experiments
2. Requirement for a wide range of data entry forms for the options involving repetitive questions, multiple selections, etc.
3. Demanding the adjustment of font type, size, descriptions, and background colors
4. Requirement of filtering, icon, and display settings to improve data readability

To maximize efficiency in the continuity of the work, the adjustments in the E2 interface have been decided upon based on E1 experiences, and the mock-up has been designed and developed on Adobe XD.

3. RESULTS

The CBP application process and the statistical data are the two sections of the findings that can be conveyed in accordance with the research methodology. The systematic presentation of the process, results, and feedback assists in ensuring that the conclusion section's evaluations are conducted in a way that is pertinent and consistent.

3.1. Implementation Processes and Outputs

Experimental application processes and outputs provide direct and indirect data for the factors examined within the scope of the research. 85% of the 3 groups of students participating in E1 are second-year architecture students, and 59% of these students are female. However, there is no significant difference in the measured factors related to these categorical variables. When the distribution of the data on collective cartography is examined after the first analysis stage, the students attending the online course are distributed across 47 urban contexts. Istanbul (40%), Izmir (7%), Konya (5%) and Ankara (3%), are the cities with the highest intensity. During the term, it was reported that students changed their places due to pandemic conditions. In the general distribution of the platform, it is clear that there are cities with distinctive characteristics from various climates and geographies. This intensity can be analyzed through the various expressions and filtering layers (Figure 4).

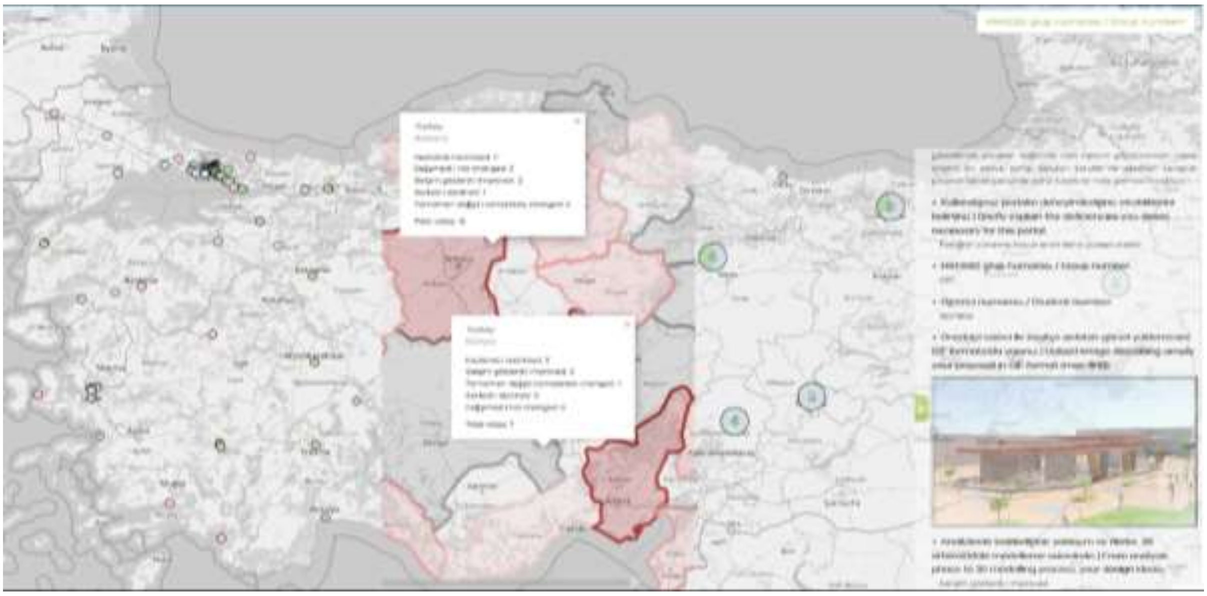


Figure 4. Single, cluster, general, and project display layers within the platform (Author)

Some statistics stand out in the use of two-stage CBP. The data uploaded by the students in various categories supports the geographical diversity covering 47 cities. (1) field analysis and (2) problem type are detailed in the first stage, and (3) the design proposal is detailed in the second stage. For field analysis, it is categorized into four categories as square (54%), street (20%), park, recreation and coastal promenade (17%) and other categories (9%) including market area, stops, idle or waste areas. There are five categories of social (61%), built (9%), natural (6%), historical environment (3%) and other (multiple hybrid situations, 21%) for the prominent problem type related to the area. Adding (47%), transforming (21%), protecting (4%), removing (3%) and other (25%) forms of intervention were adopted as solutions. Therefore, (1) square, (2) social and (3) add categories constitute the majority of the general categorical distribution for E1 (Figure 5).

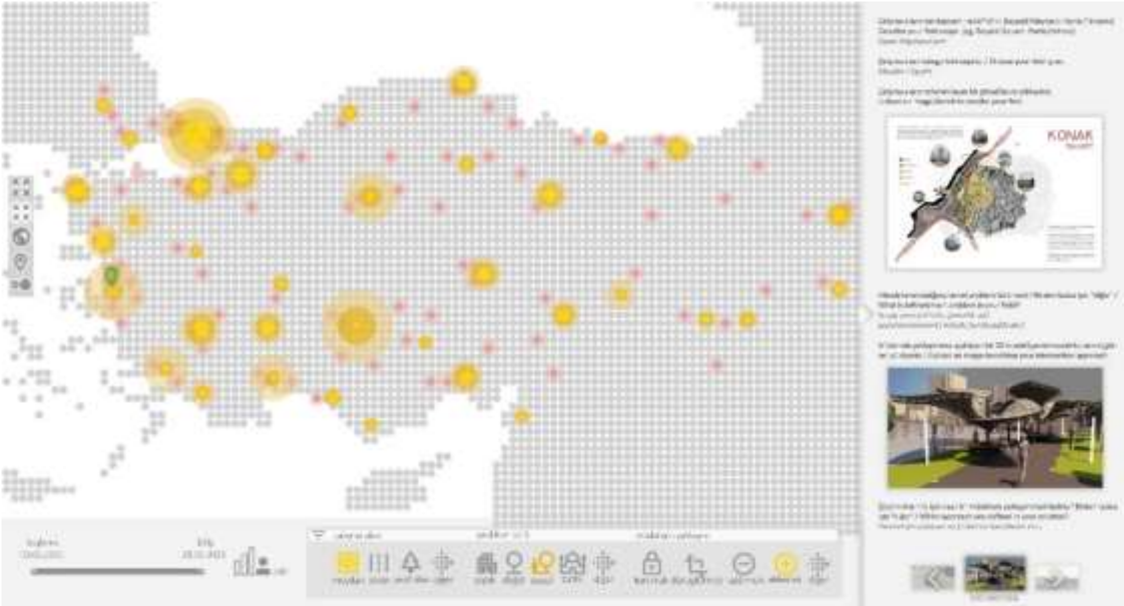


Figure 5: Display of filtered data distribution on collective cartography (Author)

Animated images (GIFs) on the platform are used to support concept design concepts, use scenarios, and parameter-based evaluations during the E1 proposal stage. Evaluations were conducted by the PPS organization's systematized list of the key factors influencing the quality of public space. Thus, the students evaluated the suggested individual approaches and design concepts based on the following criteria: sociability, uses-activities, access-linkages and comfort-image concerning the issues discovered during the analysis phase. The general distribution of the groups for the criteria based on a 7-point scale is as follows (Figure 6).

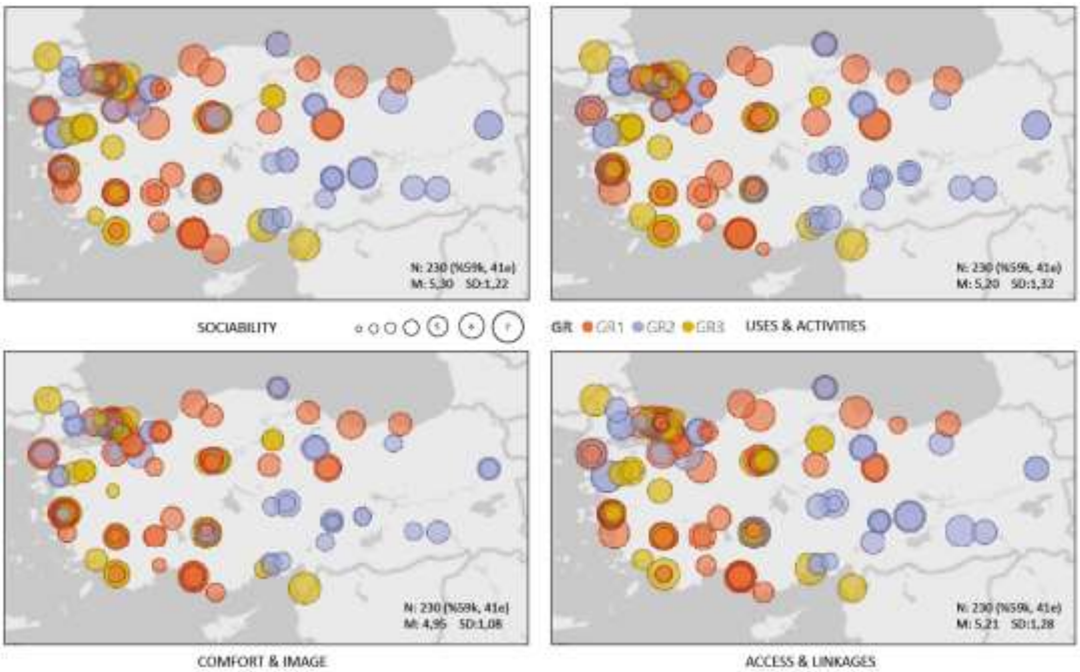
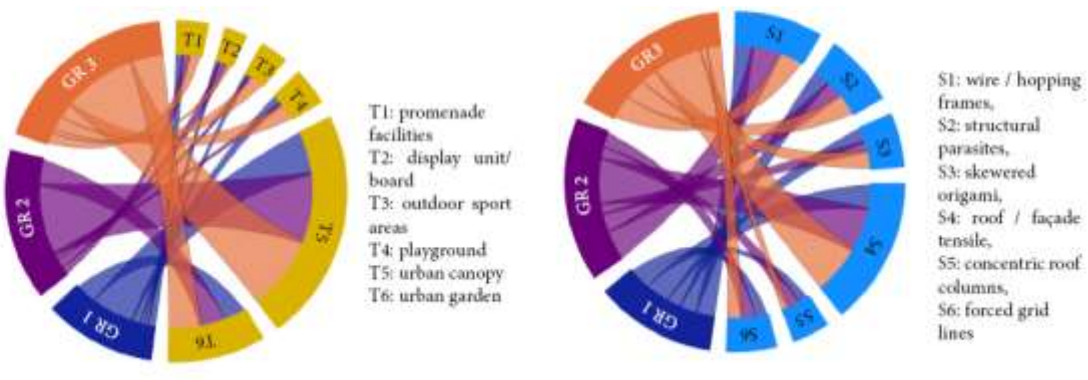


Figure 6. Criteria evaluations by groups (created in Power BI by author)

The process, which includes the E1 analysis and proposal stages, was completed in 2021 in the online learning environment. To support the results gained in this study and to address any shortcomings, the experiment was redone with interface modifications. Both examinations were carried out within the scope of the same course, as stated in the methodology section, and the effects of the modifications were observed.

The project areas for the E2 analysis phase, which was carried out in 2022, are concentrated around the Historic Peninsula, Galata, Beşiktaş, Üsküdar, and Kadıköy. The general distribution is spread over a wide area from Bakırköy to Adalar and Tuzla. For area analysis, it is divided into four categories: square (68%), street (4%), park, recreation and coastal promenade (9%) and other categories (19%), including market area, stops, idle or waste areas. The prominent and repetitive problem types related to the field in E1 were categorized as physical, social, and environmental for E2. Poor accessibility (6%), disused spaces (20%), heritage (4%), lack of inclusion (8%), limited use (19), uncomfortable (16%), microclimate (4%), greenness (18%) and place attachment (5%), are the sub-categories listed here, with the ratios indicated in the area study.

With the knowledge and insights from the E1 proposal stage, a content framework with more detailed and comparable categories was developed for the E2 proposal stage. Apart from the animated visual that illustrates the design concept, a detailed analysis is provided in the constructed format: T-proposal types (urban canopy, outdoor sports areas, urban garden, display unit/board, playground, promenade facilities, etc.), C-contextual parameters (view and topography, cultural, existing buildings, walls and borders, orientations, climate, circulation, etc.), D-design parameters (form production, functional program, positioning, scaling, material selection, structural type, etc.), S-structural types (skewered origami, structural parasites, forced grid lines, roof/façade tensile, wire /hopping frames, concentric roof columns, etc.), and M-materials (timber, textile, composite, concrete, stone, steel, etc.). The general distribution under categories can be examined by their intergroup or categorical relations (Figure 7).



(a) (b)

Figure 7. Proposal types (a) and structural types (b) in the E2 content distribution by groups (Author)

Students are able to query or filter about their subject or other projects working in the immediate region through the platform. The platform includes concept design ideas supported by animated visuals (GIF) and explanations related to parameters (Figure 8). A variety of detection and design proposals for public spaces attract attention, particularly for E2, with the possibility of archiving the previous year. With the filtering option, results for any parameter can be displayed in the analysis and proposal database. Thus, they can examine other projects and critiques that relate to their problem area and approach.

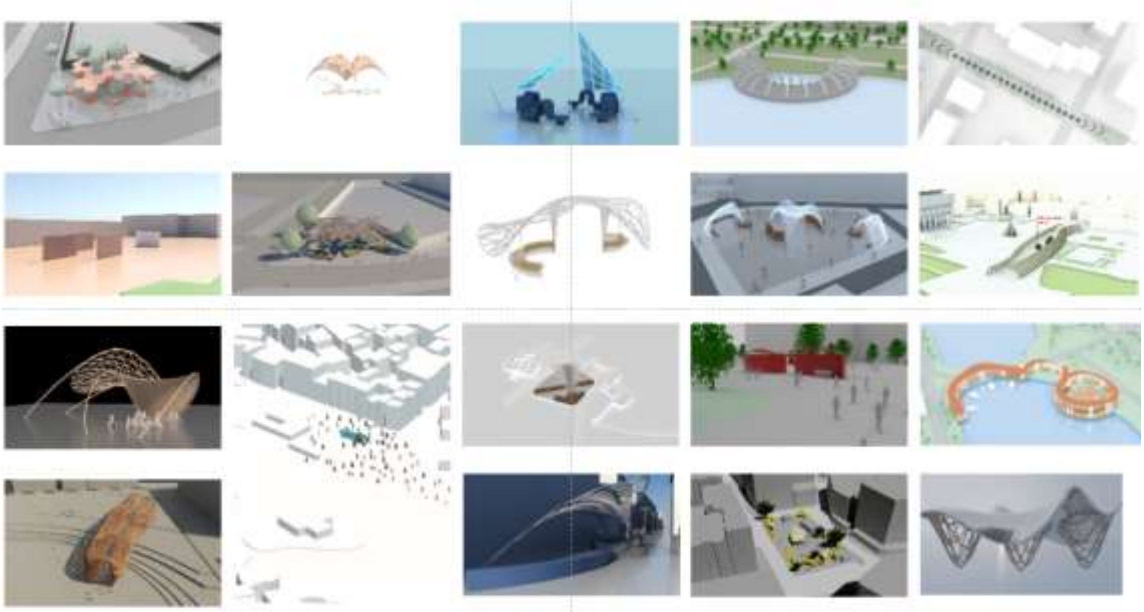


Figure 8. GIF composition showing design suggestions filtered in E2 interface (Author)

Experiment processes (E1-E2) and outputs are crucial in observing CBP effects and detecting deficiencies. This process takes into account the instructors' and course assistants' criticisms and comments. On the other hand, the effects of factors are intended to be measured more clearly by conducting surveys of the participants.

3.2. Statistical Findings Based on Participant Experiences

The preliminary survey conducted during the development of the CBP and detailed in the introduction points out the problem. The level of interaction factor (LIF) can be highlighted in this context as it is related to the basic function of CBP (Figure 9).

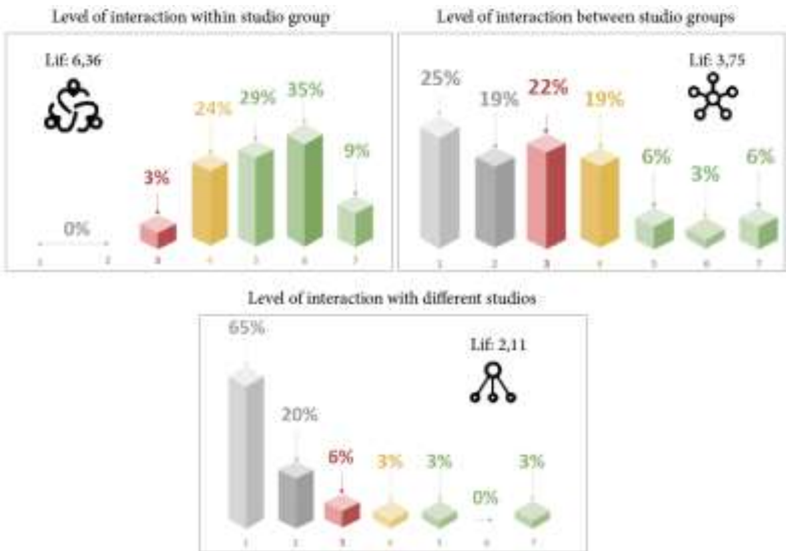


Figure 9. Different dimensions of interaction level obtained from survey results (Author)

The survey findings were imported into the SPSS environment after application and evaluation. This was done so that the effects of the three components and different expressions of platform utilization could be analyzed. The mean, standard deviation, and positive level for findings based on a 5-point Likert scale are shown in Table 1. In addition, the Tukey test is used in dataset analysis that meets the variance homogeneity condition. Differences are observed in the expressions of idea generation, sharing, and evaluation among the groups. There is no significant difference in other expressions (Table 1).

Table 1. Analysis of survey data by the author

Factors	Items	Participants (N = 230) M	SD	Level of positivity	Anova Tukey HSD Test GR1	GR2	GR3	Sig.
(1) Interaction	(1) Within / between groups	3,4	1,2	% 72,8	,040	-	,040	**,048**
	(2) Level of participation	2,9	1,0	% 56,8	-	-	-	-
	(3) Form of interaction	3,8	0,9	% 89,7	-	-	-	-
				% 73,1				
(2) Ideation	(1) Sharing	3,4	1,2	% 76,9	-	,020	,020	**,025**
	(2) Ideation	3,0	1,2	% 65,1	-	-	-	-
	(3) Discussion	3,6	1,1	% 82,6	-	-	-	-
				% 74,9				
(3) Assessment	(1) Assessment	3,7	1,1	% 86,7	-	-	-	-
	(2) Transparency	3,7	1,1	% 87,2	-	-	-	-
	(3) Open access	4,1	0,9	% 93,8	-	,035	,035	**,024**
				% 89,2				
Mean		**3,5**		**% 79,1**				

Evaluations that measure the expressions included in the factors with a cut-off point of 3 or higher are regarded as satisfactory. By thoroughly analyzing each statement to identify the significant distinctions and the relationships between them, it is possible to analyze the positivity levels of each claim in this approach. Among the findings, 'open access' (93.8%) had the highest level of positivity and 'class participation' (56.8%) had the lowest (Figure 10).

Figure 10. Detailed analysis of the level of positivity in the survey results (Author)

Regarding the E1 data entry and display interface experience, there are quantified expressions. Here, open-ended responses to the initial survey (n:230) were compiled under categorized headings such as "preview" and "location pinning." Then, using results from a second survey, statistical correlations between these categories were discovered. The prominent categories are respectively uploaded file size and format (71%), data display/review on the platform (68%), location pinning (64%), interface experience (64%), data updating and editing (61%), and viewing platform on mobile analysis (51%), graphical icon-like representations (45%), data loss during internet outages (29%), comments and criticism (29%), archive feature (26%), etc. as a distribution. According to the research, customization is a contributing factor in several of the major interface problems. These evaluations reveal the effects of the interface alteration between E1 and E2 (Figure 11). Values given as a percentage refer to participants' reports of the same issue. The approach points in the yellow region are intensifying toward 0, indicating that E2 customization has reduced the shortcomings.

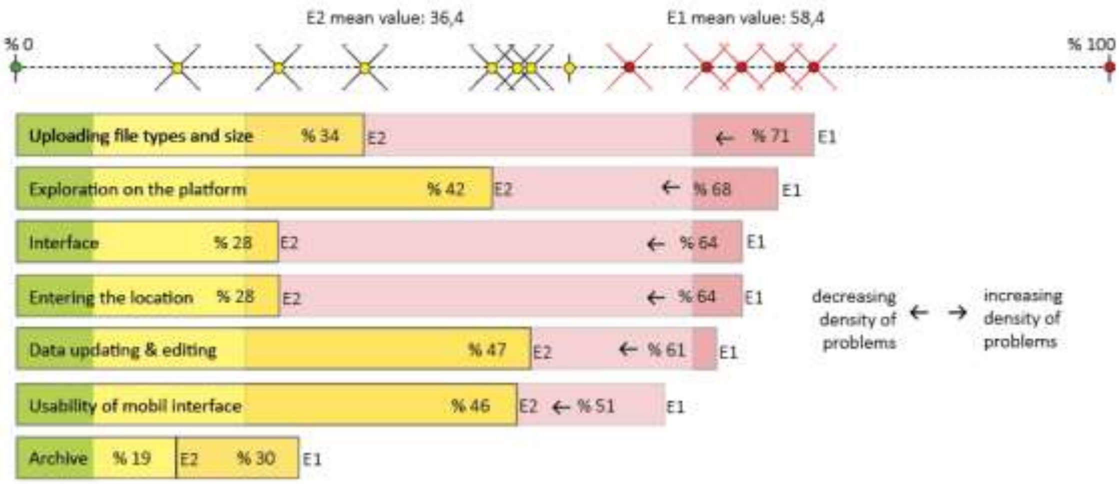


Figure 11. Graph of problems/deficiencies related to the interface usage of the platform between E1-E2

All measured values in the survey results repeated after the second experiment (E2) show an increase. The levels of idea generation and class attendance had the biggest increases. These value increases can be linked to improving (customizing) the interface and including the platform's archive from the previous year. (Table 2). With an independent sampling-based T-test, comprehensive inter-statement findings for E1–E2 can be explored. This illustrates how all of the expressions varied significantly.

Table 2. Change between proposal stage first and second application factors (Author).

	Factors	Interaction			Ideation			Assessment			M
E1:	items	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	
	M	3,4	2,9	3,8	3,4	3,0	3,6	3,7	3,7	4,1	
	avg.		**3,4**			**3,3**			**3,8**		**3,5**
E2:	items	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	
	M	3,8	3,7	4,2	4,3	4,1	4,1	4,1	4,2	4,4	
	avg.		**3,9**			**4,2**			**4,2**		**4,1**
	t-test sig.	,001	,000	,001	,000	,000	,000	,000	,000	,002	

4. CONCLUSION

Findings from the process, output, and participant experiences demonstrate the CBP strategy's potential to transform crises into opportunities while being straightforward and practical to execute. The findings regarding the three main factors examined in the context of E1 can be evaluated respectively:

- The interaction factor findings confirm the positive effect for all three groups (GR1,2,3). In contrast to other expressions, the low degree of positivity for class participation would be attributed to a variety of factors. These factors include challenges with adaptability brought on by pandemic conditions. The key element in this situation can also be studied by looking at the mass structure of the student population for each group. CBP thus appears not to be sufficient to promote full participation in the course, even though it catalyzes a variety of causes and expressions. A comparison of active experiments in this area would provide a clearer conclusion.

- The interaction factor for idea generation was found to be close to the average level of positivity (74.9%). In contrast to other expressions, group differences in 'sharing' can be explained by factors like student numbers (GR1,2-TR; GR3-EN students are fewer than GR1) or the course's language. However, the broad terms do not significantly differ among the groups. The benefit of using CBP for idea development can therefore be underlined as a point of agreement for all groups.

- The evaluation component has the highest level of positivity (89.2%) when compared to the other factors. Open access has the highest value due to its widespread acceptance. It is anticipated that this potential will increase as the archive becomes a more diversified resource, depending on how long CBP usage continues. Scoring the design proposal according to the criteria for the following stage of the platform, which is integrated into the course as a modular, provides the opportunity to support self-evaluation. The CBP's development of the rubric function is one of its objectives since the discipline of architecture benefits from the objective assessment of project proposals and the transparency principle. Mockup studies continue to demonstrate how an analytical system can be created and assessed using the platform's evaluation feature. This is a draft idea for developing the framework of a system that can adapt to diverse studio objectives. For instance, two key evaluation criteria of the course are the design proposals created for the public space in the experiments conducted under the ICS (2021, 2022) and the use of computational design tools in this process. A wide range of sub-parameters can be used to structure these criteria. At this point, the platform can be used to support the legibility and transparency of the uploaded content and evaluation criteria (Figure 12). This parametric assessment method is expected to enable straightforward searching, filtering, and reviewing of the content as the platform archive expands. Figure 12 shows the graphical maps of the projects in Istanbul based on eight criteria. The priority factors selected in the filtering section either emphasize the associated projects or, in a time-saving manner, push many projects into the background.

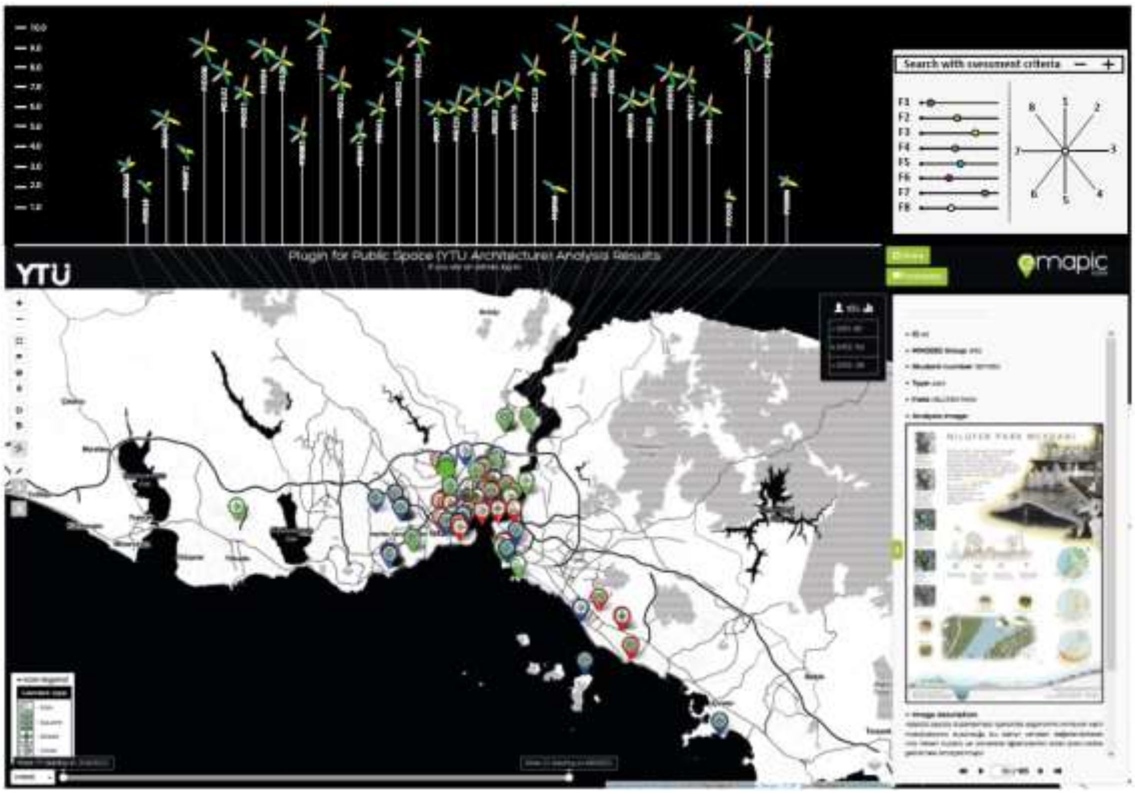


Figure 12. Mockup of the evaluation function of the platform

In the context of the same course, it is possible to review experiment findings that were abandoned as E1 and E2 along with various scale/context, environment, archive, and interface customizations:

- Despite the fact that E1 and E2 were tested on two distinct scales, "Square" is the most chosen study area for both E1 (56%) which includes cities across Turkey and E2 (68%) which is limited to Istanbul. In terms of the square, it can be seen that E1 manages social dimensions more effectively than E2, which has disused spaces (20%), limited use (19%), and greenness (18%) in the first three. Approach, function, structure, material, and design factors all show both similarities and contrasts. As a result, the study's repeated in many scales and situations both demonstrates the range of its CBP outcomes, or richness, and promotes the development of novel methodologies.

- A few assertions after E2 also merit notice, in addition to the overall statistical findings: The intra-group and inter-group CBP effects are similar (m: 3.87–3.78) in the expressions that comprise the interaction factor, with the intra-group interaction effect being greater. The CBP needs in the face-to-face and online learning environments are similar (m: 4.14-3.94) and are higher in the online environment according to the expressions included in the Ideation factor. CBP can therefore be beneficial in hybrid and face-to-face design studios, especially in lectures that are attended by larger numbers, although it was created in a pandemic environment.

- Providing more definition of the course process through open-ended questions answered concerning the advantages and potential of the platform used, being informative about other projects and approaches, enhancing in-class and intergroup interaction, providing a transparent process for evaluation, and applying it over an extended period. There are many positive statements, such as the potential to generate a resource. Although these evaluations for E1 and E2 are similar, the archiving potential and ability to view other period projects (82%, there is agreement in this statement) and support for idea generation (70%), stand out.

- Interface improvements are evaluated separately and compared across E1-E2. With the beta version used in E1, the platform, which is widely used for survey studies, has limitations in research, especially related to the interface. In this direction, it is predicted that improvements such as the ability of the executive to organize and customize the layers, the ability of the students to make corrections and evaluations, the variety of questions and formats, the preview and filtering options, and the search and analysis in the archive will make the process more efficient. Therefore, it is imperative to observe the impact of interface customization on the identified factors of CBP usage. Here, the revised interface has a significant positive effect on both the user experience (Figure 11) and the factors (Table 1). These customizations and tests will continue in the later stages of the study in line with E2 feedback.

The use of the results of the study (online) in education can be evaluated in similar studies in the context of architectural ICT tools and the collective cartography method. This multi-perspective approach is crucial to discuss the pervasive impact, unique impact, and benefits of the study:

- The research findings, ranging from an online design studio for first-year students in Australia [13] to the limitations of field trips and field study in pandemic conditions for architecture students in Slovakia [14], as well as student satisfaction with the original strategy tested by Jordanian universities in its context. It contributes to a common and up-to-date discussion, such as studies conducted in different contexts, to the assessment of the difficulties in online architectural education across Nigeria [15].

- Ongoing research related to the first author's doctoral thesis is being assessed at various levels (international, national, urban, and neighborhood) (Figure 13). With regard to the factors examined here, a goal is to identify the potential of the collective cartography method in terms of collaborative design. This is done through working together and producing in varied educational contexts. Findings from this study provide supporting evidence for the assessment of a range of factors measured in other contexts. For example, CBP, which is used as a tool for environmental awareness and transparent assessment on an international scale, is tested as a collaboration and coordination tool for field studies carried out within the scope of the Architectural Design Introduction studio at a neighborhood scale (Kuzguncuk) and as a collective decision-making tool for another related participative workshop.

Figure 13. Development of the study on different scales and factors (Author)

According to one of the related studies, restoration and determination studies within architectural education were examined using a similar method based on the collaborative mapping. An examination of the priorities in the context of rural locations reveals a number of significant features, including offline data entry. Data collection in various layers and forms, or the use of mobile devices, appears to be the main priority for the CBP, which was evaluated for fieldwork as part of the architectural design course.

This study demonstrates that CBP, which is designed and assessed in a variety of contexts and based on certain factors, has significant potential to contribute to the development of online and hybrid architectural education. In addition to assessing the feasibility of its distribution throughout the full period and the depth of its archive, it must also be designed with modular integration. Experimental applications can be used to ascertain and enhance the constraints or shifting priorities identified here.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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A DECISION SUPPORT SYSTEM PROPOSAL ON THE USAGE OF EXTENDED REALITY SDKS IN AEC DISCIPLINES

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ABSTRACT

Technology is employed in the fields of architecture, engineering, and construction (AEC) for characteristics like producing visual representations and offering assistance during the building phase. Both users and creators of these tools are able to immediately take advantage of the technology's potential as well as create a variety of workarounds for its drawbacks. Both viewpoints will be looked at in this study with regard to mobile extended reality SDKs (software development kit). By excluding the articles that did not provide the relevant information, this research concentrates solely on the papers that discuss the technological aspects of the SDK that were used, the opportunities the SDK offers, and/or the shortcomings of the SDK. The study's main objective is to compare the technological contributions made by the SDKs employed in the scope of the examined literature to the AEC disciplines and to the contexts in which such contributions are made. Through applications in literature research, this study aims to highlight the contributions of mobile extended reality SDKs to the fields of architecture, engineering, and construction. An entry-level developer can use the SDKs in accordance with his work by using the comparison diagrams, produced in this study, to consider the relationships and comparisons between them, as well as to build a framework for what uses should be made in which fields. The technological capabilities and constraints of SDKs have an impact on how research is designed. Making relationality diagrams on the SDK to use and the effects it will have throughout the research phase is also crucial. As a result of the research, SDKs permit flexible uses in a variety of sectors, and their use also financially and logistically supports literature studies.

Keywords: Architecture Engineering Construction (AEC), Decision Support System (DSS), Extended Reality (XR), Mobile Augmented Reality (MAR), Software Development Kit (SDK)

1. INTRODUCTION

Emerging technologies have an impact on design methodologies, production and building procedures, and representational strategies in the discipline of architecture, engineering, and construction (AEC). Despite the potential of augmented reality (AR) in this industry, the experts there have not fully embraced its dynamic notion. Collaboration between various stakeholders is how AR improves work productivity.

Although AR has the potential to enhance real world objects, it also has several restrictions. The quality of characteristics utilized for the model integrated with AR is constrained by and influenced by the software's quality. Solutions can accomplish the goal by being aware of the strengths and weaknesses of the software used in AR applications. At this stage, integrating the use of the software allows for effectiveness due to the use of each software's opportunity in a particular field or the supporting of each software's deficiencies with others. By employing several Software Development Kits (SDKs), more sophisticated AR Applications can be produced. A Software Development Kit (SDK) is a set of tools and libraries for creating programs that are used to create software. Mobile devices are widely available, user-friendly, and reasonably priced, making widespread and democratic adoption of mobile augmented reality applications possible. Due to these characteristics of mobile devices, the article focuses on their development environment, namely SDKs.

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With regards to capabilities like tracking, recognition, and rendering, SDKs vary from one another. The location registration method can essentially divide AR technology into two categories: image-based AR, which recognizes feature points from images, and sensor-based AR, which is recorded by a sensor such a GPS. Marker-based AR and marker-less AR are the two categories that image-based augmented reality falls into, depending on whether specific markers are used. The production of an environmental map and the estimation of the self-position without using the map can both be done simultaneously thanks to Simultaneous Localization and Mapping (SLAM) technology. Here, the camera is the only sensor used by the visual SLAM algorithm. This instrument, which is widely used in robotics engineering, increases the stability of the AR tracking method. Therefore, a markerless AR algorithm is used in the created tele-simulation system [1].

How these settings can be employed in the AEC area, which cases they are used the most, and what potential contributions have been highlighted in the literature are the main study questions. Additional sub-questions include: which SDK can be used effectively in which situations or fields; what kind of usage of SDK does the authors prefer in their research; what are the technological advantages and disadvantages of the SDKs; what opportunities do the SDKs offer in the AEC fields; and which hardware, software, and programming languages are used in conjunction with the SDKs.

By providing answers to these queries, it is possible to identify the SDKs' potential contributions and their limitations to the AEC area. This gives the user looking for "a reasonable program" for "a certain purpose" at the start of their study. The common and dissociating aspects of the SDKs are used in this study by comparing them.

Through applications in related literature, this study aims to highlight the contributions of mobile extended reality SDKs to the fields of architecture, engineering, and construction. It then builds comparison diagrams based on these findings. This approach is crucial for developing a foundation for what kinds of uses go where and for being able to compare and contrast the software development kits that a newbie developer might employ in accordance with his work.

The study's main focus is on the technological contributions made by the SDKs employed in the literature under consideration to the previously listed disciplines as well as the contexts in which such SDKs are applied through flowcharts.

Applications for augmented reality (AR) use a variety of software development kits (SDKs), including ARCore, Vuforia, ARToolKit, ARKit, WikiTude, LayAR, Kudan, FaceSDK, SLARToolKit, FLARToolKit, OsgART, Droid AR, Augment, Aurasma, Metaio, BazAR, D'Fusion, Gamma AR, Tango, Firebase, Estimote Indoor Location SDK, Fologram, Metaio and xBIMToolkit. Some SDKs, such as Tango or Metaio, are excluded from this research because they were taken off the market. Therefore, only Vuforia, Fologram, ARCore, ARKit, ARToolkit, Gamma AR, Kudan AR, and xBIMTools are included in this study.

Vuforia, ARCore, ARKit, and ARToolKit are a few of these SDKs that are often used. Because of characteristics like text and environment recognition, scanning, and object creation, Vuforia is mostly used to recognize many types of visual objects. Motion tracking, environmental recognition, and light estimation are three of ARCore's key capabilities. Light estimation, TrueDepth camera, visual inertial odometry, scene identification, and rendering optimizations are all made possible by ARKit. Single or stereo cameras for position/orientation tracking, tracking of plain black squares, tracking of planar pictures, camera calibration, optical stereo calibration, and support for optical head-mounted displays are some of the unique features of ARToolKit [2]. The most popular program for the creation of AR applications, Unity 3D, is compatible with all four of these SDKs. The emphasis is on the features of software rather than its price or widespread use.

This study is divided into the following sections: an introduction section that includes the problem, hypothesis, aim, and scope; a materials and methods section expressing the methodology by focusing on literature review in the fields of architectural and urban design, construction, and digital fabrication; a section on the technological features and related tools of the SDKs (such as hardware, software, programming languages); a section on the opportunities they offer and the drawbacks of the SDKs; and a section on the results and discussion and finally conclusion section (Figure 1).

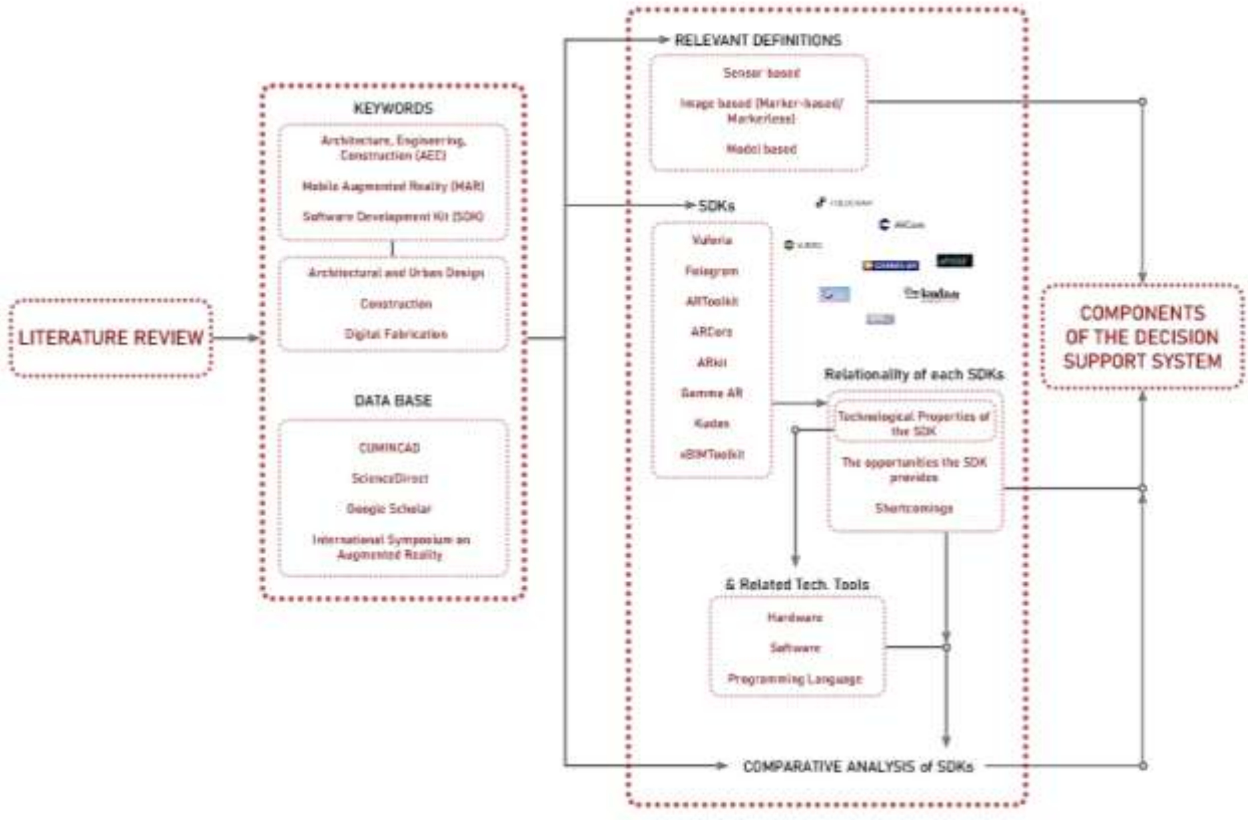

Figure 1. General framework of the study generated by the authors.

2. MATERIALS AND METHODS

This study's methodology focuses on the technological features of the SDKs, as well as associated tools (such as hardware, software, and programming languages), opportunities they present, and the shortcomings of the SDK. Comparative charts make it simple to understand how SDKs relate to AEC fields, software, hardware, programming languages, and technological attributes.

Only the case studies that created AR applications and used them in their studies are examined in the literature review. The research's data source is a collection of publications from the fields of architecture, engineering, and construction that discuss the SDKs used by mobile augmented reality applications.

184 research papers published between 2010-2021 are reviewed on ScienceDirect, International Symposium on Augmented Reality, Google Scholar and Cumincad database is taken from annual conferences of the Association for Computer Aided Design In Architecture (ACADIA) and its sibling organizations in Europe (ECAADE and CAAD Futures), Asia (CAADRIA), the Middle East (ASCAAD), South America (SIGRADI) and International Journal of Automation and Computing

(IJAC). Studies in these indexes contain terms like mobile augmented reality apps, augmented reality SDKs, and augmented reality applications in architecture, engineering, and construction (AEC) (Figure 2).

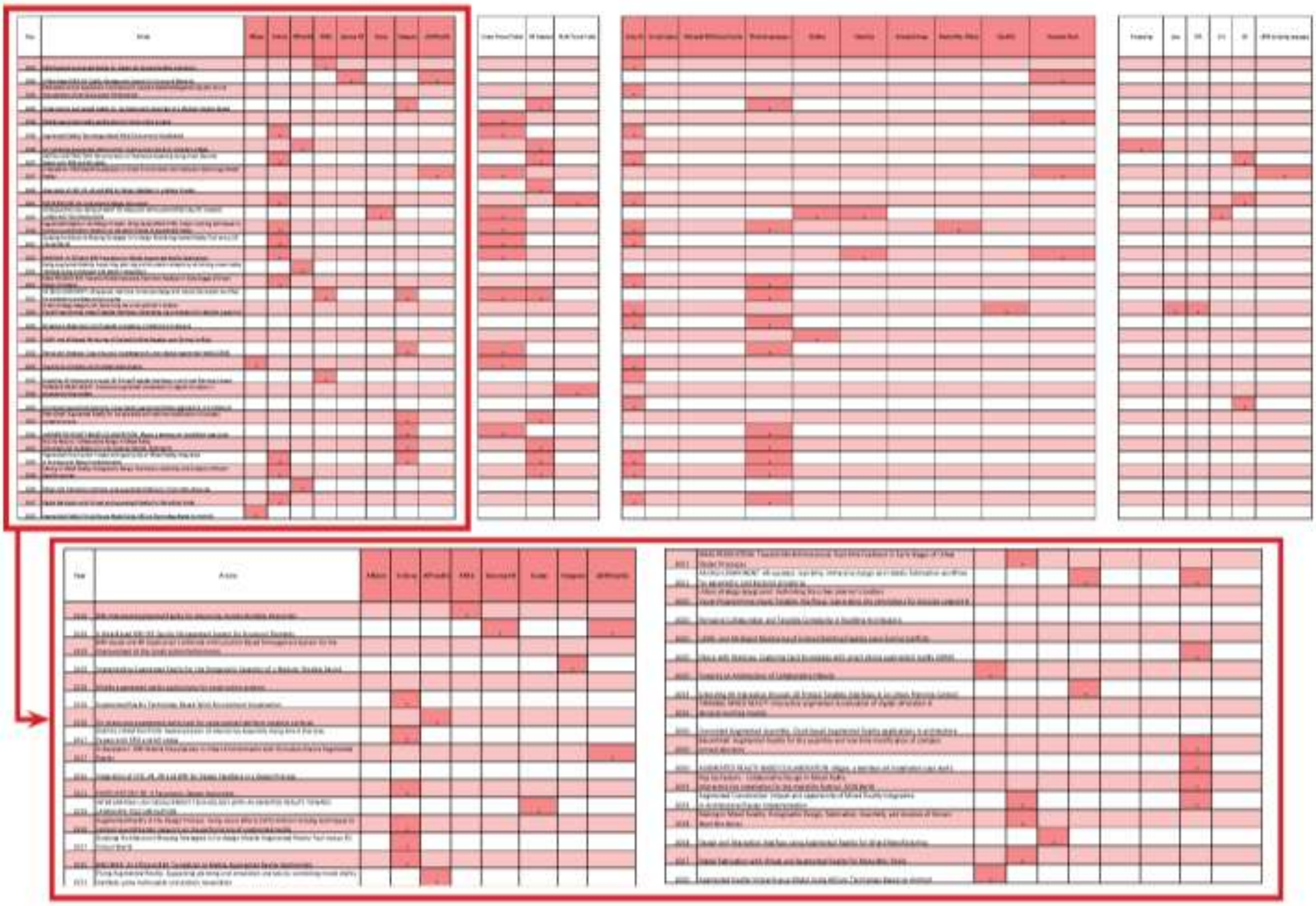

Figure 2. Literature review (filtered & generated by the authors).

In the papers pertaining to this particular field, the SDKs ARCore, Vuforia, ARToolKit, ARKit, Augment, Gamma AR, Kudan, Tango, Firebase, Estimote Indoor Location SDK, Fologram, Metaio Creator, and xBIMToolkit are examined in the first phase of the study. The Metaio Creator SDK is removed by the author because Apple acquired it in 2015 and it is no longer available. Due to their accessibility, Tango, Firebase, and Estimote Indoor Location SDK were also excluded from consideration.

Four categories—BIM/Construction/Building Physics, Architectural Design, Urban Design, and Digital Manufacturing—are used to group the articles. 28 articles on architectural design, urban design, BIM/construction/building physics, and digital manufacturing are reviewed in terms of the technological qualities of the SDKs, the opportunities they present, and the shortcomings of the preferred software (Figure 3).

Figure 3. Outputs of the SDKs in the literature review, generated by the authors.

2.1 Vuforia

This subsection focuses on nine articles that reflect how Vuforia's technological features are used, the benefits it offers, and its shortcomings.

Utilized technological features: According to Yao et al., the tracking technology of the computer vision function keeps the camera in focus. With the help of this technology, it is possible to overlay virtual and physical objects on a single real-time video [1]. In their description of the position tracking function, Abe et al. stress that it does not depend on the type of marker and can identify any marker [2]. Additionally, it features SLAM (Simultaneous Localization and Mapping) function, and the app uses AR markers to determine relative position. As a result, the location is very precise. This SDK is used by Silcock et al. as the computer vision technology tracks and recognizes 3D objects as well as photos in real-time [3]. Additionally, Vuforia permits the use of numerous trackers in the same video scene. The markers can be altered. But they ought to have sharp edges. Researchers might employ paper as virtual buttons with the aid of Vuforia, making the program more interactive. Yao et. al. drive Vuforia SDK again in their next research [4]. Because it enables the assembly of various marker types inside a single Unity 3D environment. Vuforia is run by Gül and provides a library of target objects, object identification, and additional tracking functions [5]. Sun et al. selected Vuforia due to its simplicity of use and widespread adoption [6]. Goepel uses Vuforia with HoloLens and utilizes the feature of depth mapping of this SDK [7]. Jahn and his colleagues use the Vuforia SDK to create a real scale (1:1) model. It enables the physical model to be built continuously without having to go back to the computer [8]. To sum up, utilized technological features of Vuforia is the tracking technology/position tracking, marker technology, it’s library, depth mapping and synchronization.

The advantages of the SDK: Yan et al. replicate the wind's movement around a building, giving the designer the data for the early design stage [1]. Using Vuforia SDK, Abe et al. develop a system for synchronizing the physical and digital models [2]. Within the AR environment, Silcock et al. develop tangible and interactive user interfaces [3]. With the use of these user interfaces, users can design different house typologies. On the other hand, Gül develops a program that enables designers to move, rotate, scale, and alter the color of fundamental 3D geometries [5]. Sun et. al. use Unity in real-time, and the massing will change color as soon as the physical site models are modified [6]. For 1:1 scale models, Goepel creates a holographic instructor [7]. According to Jahn et al., 1:1 model construction is aided by dynamic instructions rather than static blueprints [8]. Chaltiel et al. use Vuforia to create an

AR application that highlights how the user's activities affect the structure [9]. Vuforia is applicable to many fields, including digital fabrication, building physics, urban design, and architectural design.

The SDK's shortcomings: In some registrations in the literature, like the study by Abe et al., the registration can result in a system fault. The deep consideration and calculating processes are also criticized in this piece [2]. Silcock claims that this procedure can take a long period [3]. Due to its direct compatibility with HoloLens, Goepel prefers Fologram for holographic instructions in digital fabrication [7]. However, there was no access to the recently developed software Fologram, thus, the author used Vuforia instead. The first issue with Vuforia is the registration issue brought on by the markers. Research takes time to complete. Additionally, using an HMD (head mounted display) with Vuforia is ineffective, and using Fologram in this situation could produce better results.

2.2 Fologram

This section focuses on seven publications that illustrate how Fologram is used technologically, the benefits it offers, and its shortcoming.

Utilized technological attributes: Fologram, according to Kontovourkis et al., enables interaction in the real world by augmenting, superimposing digital results and the digital information that goes with them [10]. Furthermore, this SDK allows the development and control of parametric structures. Another useful technological element of this SDK is its integration with Grasshopper, HoloLens, and smartphones [11-12]. It facilitates coordinated digital building [13]. This SDK is used in the literature because of its simplicity of use, which is another important factor [14]. It enables navigation between the various CAD/CAM phases and acts as a reference during the assembly step [15]. The Fologram SDK recognizes user gestures, screen taps, device position, it has a customizable interface on mobile phones and HoloLens, and the Fologram SDK offers the opportunity to interact with Grasshopper in the AR environment [11]. Fologram's coordinated use with Rhinoceros/Grasshopper is the primary justification for its use.

The SDK's opportunities include the simple ability to assemble sophisticated holographic structures. Construction costs and time are cut out [10]. It provides designers with an easy approach to control the robotics for the creation of manual-unachievable materials through AR, even if they lack specialized computer or programming experience [11]. It uses daylighting metrics [12]. These holographic instructions make it feasible to create anything precisely and quickly. It assists unskilled laborers in the assembly of complex structures [13-15]. Collaborative and creative production is possible [14].

The SDK has a few shortcomings, one of which is that users frequently have to rotate their heads to see all of a visual object in front of them. When live streaming or video recording takes place, there is an error in the way that virtual objects and the real world are superimposed [10]. Holograms and real-time alteration is delayed by a bad internet (Wifi) connection. Because of this, it is occasionally required to restart the device and re-scan a QR code to update the location of construction [11]. To tie the enhanced object to the specified place in a given context, it is necessary to continuously scan the marker [12].

2.3 ARCore

Two articles in the literature express the utilized technological properties of ARCore, the opportunities it provides and its shortcomings are at the focus of this study.

Utilized technology capabilities: ARCore is capable of detecting flat surfaces like floors and tables. By leveraging the facilities on the user's smartphone, in this case an Android device, the virtual object placed on the flat surface is given an anchor that is used to mark the position of the object against the surrounding environment [16]. Another advantage of this SDK is that it operates without any branding or watermarks [17].

The SDK's advantages include the ability to recognize corners, wall borders, horizontal and vertical planes. Virtual items can also be rotated, moved in accordance with the identified planes, and scaled for a closer observation [16]. It enables playing with "Collaborative Objects" in real, augmented and mixed realities [17].

The point cloud technology built into ARCore can detect a variety of textures, but it is difficult to detect monocolors, such as a white color. In the case of a dark room, it is also challenging to detect the horizontal and vertical planes because point clouds cannot detect the texture in such circumstances [16].

2.4 ARKit

Three articles express the utilized technological properties of ARKit, the opportunities it provides and its shortcomings are at the focus of this study.

Utilized technological features: The tracking system and gyroscope feature of ARKit are two of its most important technical features (it corrects orientation through an electronic compass). It enables the superimposition of a BIM model, solves model registration issues, uses tracking and motion sensors to solve tracking issues in dynamic environments, aligns the virtual model with the actual building with the possibility of manual adjustments, and is applicable to both outdoor and some indoor environments [18].

The opportunities this SDK offers: Ashour et. al. develop an application with a wireframe shader. In contrast to opaque shaders, which cause the virtual model to occlude the real-world objects, wireframe shaders shield users from hitting stationary items and oncoming traffic [18]. The user interface shows the GPS accuracy data, compass information, and geographic coordinates. Instant access to built environment-related information is made possible by this application [18]. By filtering out any buildings that were constructed around the same time as the selected building, the interface can represent changes in the physical model [19].

The SDK's shortcomings include GPS's poor accuracy as a result of its registration process. It is particularly inaccurate inside. There is a slight misalignment when moving from an outside situation to an inside environment. The computations for the IMU (inertial measuring unit) contain accumulated inaccuracies [18]. The incorporation of additional tracking methods, such as computer vision and AI (Artificial Intelligence), is this SDK's second limitation [18].

2.5 ARToolKit

Three articles express the utilized technological properties of ARToolKit, the opportunities it provides and its shortcomings are at the focus of this study.

Utilized technological attributes: Camera tracking and calibration should be precise when using the ARToolKit SDK. Otherwise, the real world's augmented guiding lines are shifted. The output results could be impacted by even minor variances and assembly errors in the camera. As a result, using the two-step calibration method offered by the ARToolKit library, each camera was calibrated separately. The majority of AR systems use just one camera. Two cameras work together in the Fazel & Izadi's system to prevent view obstructions, which frequently happen due to user movements or other potential obstacles during construction. Two cameras—one fixed and one portable—make up the capturing equipment [20]. The second camera was a component of an Head Mounted Display (HMD), while the fixed camera was attached to a CPU (in this case, a laptop running AR programs). The proposed tool was marginally quicker than the previously reported robotic fabrication techniques in this research.

The SDK's opportunities: ARToolkit provides novel, viable, and reasonably priced ways to build free-form modular surfaces [20]. Users can draw 2D curves on an existing object and then use straightforward interactions to turn those 2D curves into 3D objects. Users can interact with the designed touch-based interactive gadgets in a natural and simple way [21]. It helps to integrate architectural design with urban planning [22].

The SDK's shortcomings include the necessity of locating the object coordinates because of the use of markers. Small-scale buildings, like those of Fazel and Izadi, can easily use this technique [20]. This approach is rigid and harder to use on a broader scale. Additionally, there is limited support for occlusion [22].

2.6 Gamma AR

In one article, the technological capabilities of Gamma AR are discussed, along with the benefits and shortcomings it present.

The following technological features are used: Gamma AR updates task statuses, enabling input quality assessments on-site, visualizes the BIM Model, directly uses the IFC format, and provides the option to obtain element-specific information by simply clicking on the object. The BIM model is superimposed on the reality on site using this application positioning system's markerless tracking method, which leverages depth sensing. The inspector must select the floor and the room for positioning before selecting two corners of a wall or column in the model to superimpose it on reality. The advantages of this SDK include increased design comprehension, easier information access, effective control, and cost savings. The positioning accuracy issues and the wall model's occlusion of real items are the SDK's limitations [23].

The SDK allows the integration of augmented reality (AR) and building information modeling (BIM) technology [23].

The SDK's shortcomings include the fact that it is challenging to accurately superimpose the pins in order to create an AR experience. Occlusions create difficulties [23].

2.7 Kudan AR

In one article, the technological capabilities of Kudan AR are discussed, along with the benefits and shortcomings they present.

Utilized technological attributes: Kudan uses Simultaneous Localization and Mapping (SLAM)-based markerless AR technology [24].

The system employs the SLAM-based markerless AR algorithm named KUDAN SLAM AR to accomplish the required outdoor review function [24].

2.8 xBIMTools

This study focuses on two papers that represent the technological aspects of xBIMTools that are used, the potential they present, and their advantages and disadvantages.

Utilized technological capabilities: IFC-formatted BIM models can be read, created, and viewed using xBIMTools. Two core libraries of the xBIM toolkit are xBIM Essentials and xBIM Geometry [23]. It has cloud service that extracts the external BIM Model components [25].

The SDK's advantages include its integration of augmented reality (AR) and building information modeling (BIM) technology [23].

The SDK's shortcomings include the fact that it is challenging to accurately superimpose the pins in order to create an AR experience. Occlusions create difficulties [23]. Georeference of the offline data misses [25].

2.1. Comparative diagrams of SDKs

The most widely used SDK in the field of digital manufacturing is called Fologram; other SDKs like ARCore, ARKit, ARToolKit, and Vuforia are also used. Divergent SDKs like Gamma AR, Kudan, xBIMToolKit, Vuforia, and ARToolkit are used in the literature of BIM/Construction and Building Physics domains. While Vuforia, Fologram, and ARKit are mentioned in literature on architectural design, Vuforia and ARKit are also employed in the field of urban design (Figure 4-5).

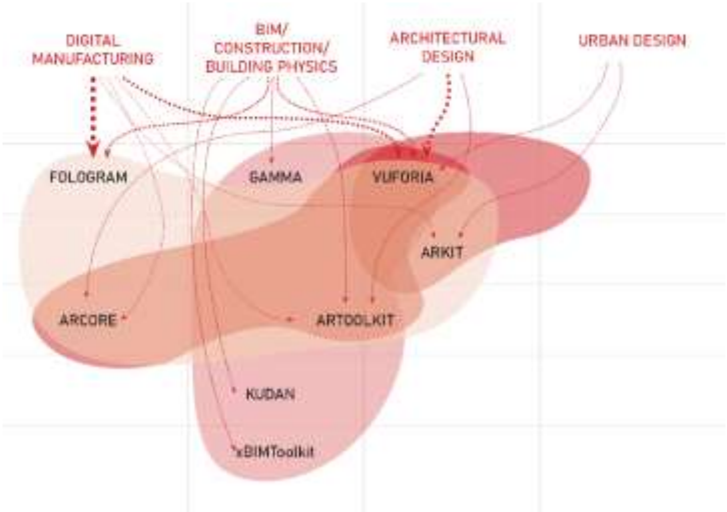

Figure 4. Relationships between the SDKs and AEC Fields generated by the authors.

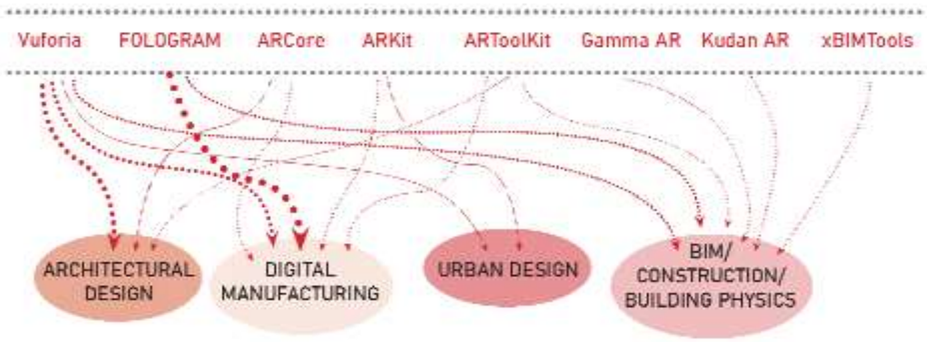

Figure 5. Relationships between the SDKs and AEC Fields generated by the authors.

While Vuforia is driven mostly by Unity 3D, Gamma AR, and xBIMTools which can also be used in conjunction with Autodesk Revit, Fologram is driven by Rhinoceros/Grasshopper (Figure 6).

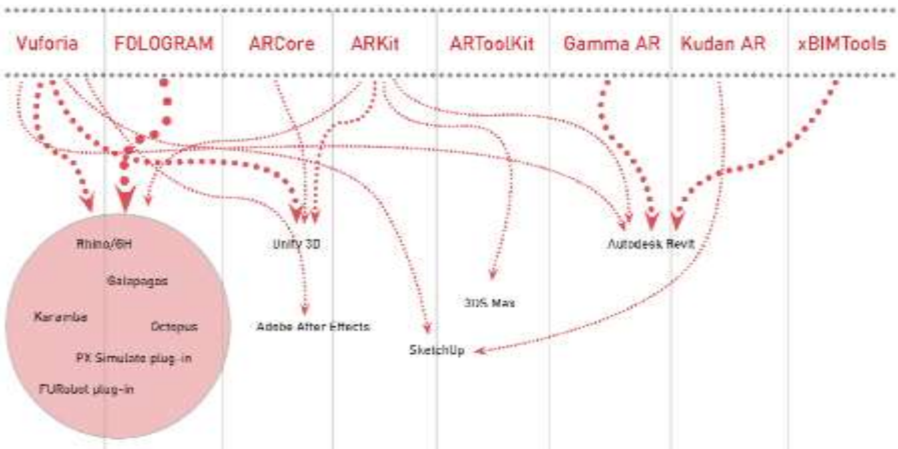

Figure 6. Relationships between the SDKs and software generated by the authors.

While smartphones and tablets are the main hardware runned with most of the SDKs, there are other tools, such as camera, multicopters, UAV camera, bluetooth and wifi enabled microcontroller, RGB Led, 3D printer, 3D scan, paper, robotic arm, smart gloves, multi touch table, head mounted display, kinect (Figure 7).

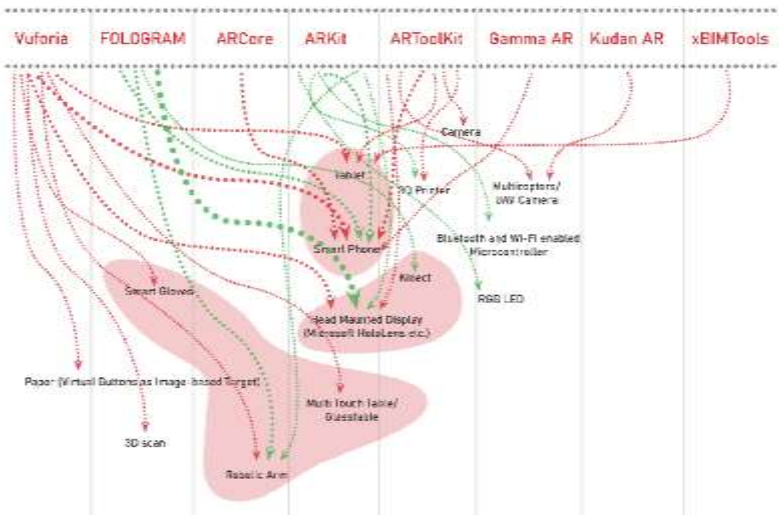

Figure 7. Relationships between the SDKs and hardware generated by the authors.

Due to their predominantly linear usage, the relationships between the SDKs and programming languages like C#, Processing, C++, and xBIM scripting language are weak (Figure 8).

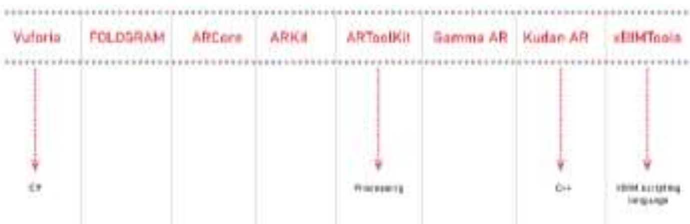

Figure 8. Relationships between the SDKs and programming languages generated by the authors.

Technological properties have a more complex relationship, because mobile devices do not have similar qualities. For instance, ARKit only works with iPhones and thus, uses the TrueDepth Camera capability (Figure 9).

Figure 9. Relationships between the SDKs and technological properties generated by the authors.

3. RESULTS AND DISCUSSION

The tools used in a research affects the design of the research. The way SDKs are used is relevant in augmented reality researches, because SDKs have different functions such as light estimation, true depth camera, tracking planar images, camera calibration, motion and position tracking, environment recognition and simultaneous localization and mapping (SLAM). When developing a research, consideration should be taken in selecting the SDK that will be employed. The goal of this study is to assist the researcher in determining which SDK is required.

In this study, Vuforia is utilized more widely while Fologram, used with Grasshopper is discovered to be the front-runner in the field of digital manufacturing. Kudan, Gamma AR, xBIMToolkit are used especially in the field of Construction and BIM (Building Information Modeling). During ARKit have true depth camera function, tracking of planar images, SLAM and motion/position tracking function; ARToolKit can also track planar images and has besides camera calibration function and ARCore has light estimation and SLAM function except tracking of planar images.

Although in the design field mostly both Vuforia and Unity are used, ARCore and ARToolKit are also utilized in some cases. Fologram is the most widely used SDK and plugin in the realm of digital manufacturing since it integrates with Rhinoceros and Grasshopper easily. In addition, ARKit, ARCore, and Vuforia are used in digital manufacturing.

The development of applications using these SDKs for architectural and urban design, BIM/construction, and digital manufacturing is crucial for the study's next phase because it will allow the testing of SDKs. The sound built into the SDKs may also be employed in navigation systems in the future to aid laypeople.

4. CONCLUSION

The studies in the literature are oriented by the state-of-the-art of mobile AR applications in terms of their potentials and shortcomings. According to the findings, using more mobile application SDKs improves research in a variety of ways. As a result of the research, it is observed that Software Development Kits are useful in a variety of sectors, and studies have shown that using these kits leads in shorter working hours, lower budget, and more accurate outcomes.

This research is constrained by 184 research publications in the AEC industry that use SDKs. These articles do not cover all SDKs, including DeepAR, Wikitude, Easy AR, D'Fusion, and ARMedia. Comparing with other SDKs will require more thorough research.

Artificial intelligence, deep learning and computer vision are required to improve the SDKs. The technological capabilities and shortcomings of SDKs have an impact on how research is designed. For this reason, it's crucial to choose the SDKs based on the area of focus. During the research phase, it's crucial to construct relationship diagrams that show which SDK should be used and what would happen as a result.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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CLASSIFICATION OF SATELLITE IMAGES WITH DEEP CONVOLUTIONAL NEURAL NETWORKS AND ITS EFFECT ON ARCHITECTURE

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ABSTRACT

Unlike traditional machine learning methods, deep learning methods that can learn from image, video, audio, and text data, especially recently with the increase in hardware power, are also increasing in success. Considering the success and benefits of deep learning methods in many different fields with increasing data, similar effects are expected in architecture. In this study, we focused on textures by going down to specifics rather than general images. In this direction, a total of 4500 satellite images belonging to cloud, desert, green areas and water bodies were classified in the model developed using deep convolutional neural networks. In the developed model, 0.97 accuracy for cloud images, 0.98 accuracy for desert images, 0.96 accuracy for green areas images and 0.98 accuracy for water bodies images were obtained in the classification of previously unused test data (675 images). Although there are similarities in the images of cloud and desert, and images of green areas and water bodies, this success in textures shows that it can be successful in detecting, analyzing, and classifying architectural materials. Successful recognition, analysis and classification of architectural materials and elements with deep convolutional neural networks will be able to facilitate the acquisition of appropriate and useful data through shape recognition among many data, especially at the information collection phase in the architectural design process. Thus, it will help to take more accurate decisions by obtaining more comprehensive data that cannot be obtained from manual data analysis. Learning the distinctive features for classification of data in deep convolutional neural networks also explains architectural design differences and similarities. This situation reveals the hidden relationship in the designs and thus can offer architects the opportunity to make creative and original designs.

Keywords: Deep learning, Deep convolutional neural network, Image classification, Detection of material textures, Architecture

1. INTRODUCTION

The architectural design process is the process of solving design problems and making decisions using data and experience. Today, with the development of computer technologies and hardware, architectural design tools and processes are also developing and changing. Therefore, these tools and methods used by architects or designers also affect the architectural design process. With the continuous development and advancement of technology, data is also increasing rapidly. Machine learning algorithms, an artificial intelligence application belonging to the sub-branch of computer science, are used to recognize these increasing data, analyze them, learn from these data and make decisions in accordance with the information they have learned. Machine learning is an artificial intelligence method that enables the computer to make inferences and gain the ability to learn with various algorithms by using mathematical and statistical operations without using traditional programming methods. Machine learning, which is used in various fields, analyzes much more data than a human can analyze and produces better results, thus making more accurate predictions. It also contributes to automating ordinary tasks and helping in decision-making processes.

The concept of deep learning emerged for the first time with Hinton and Salakhutdinov [1] proposing algorithms that can learn the properties of data hierarchically with deep neural networks. Deep learning is an artificial intelligence method that uses multi-layer artificial neural networks and is a sub-branch of machine learning methods. The use of deep learning is increasing rapidly today with the increase in

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hardware power (graphic processor units - GPU) and processing power that can process increasing data. Unlike traditional machine learning methods, it can also learn from data belonging to images, videos, audio, and texts. In addition, unlike traditional machine learning, deep learning can perform attribute extraction itself with little or no computer intervention. With deep learning, which is a sub-branch of machine learning, it has become easier to define, classify and process the increased data. Considering the success and benefits of machine learning in various fields it is expected that similar success and benefits will be achieved in the discipline of architecture.

Various machine learning methods are used to classify architectural designs and elements visually with computer vision techniques. Learning the distinguishing features for classification also helps to explain the design differences and similarities. Yoshimura et al., [2] used a deep convolutional neural network (DCNN) model to classify the works of 34 different architects, and this model divided the images into classes depending on the visual similarities measured by the algorithm. Llamas et al., [3] used convolutional neural networks (CNN) for classification of architectural heritage images and stated that the application of these techniques can significantly contribute to the digital documentation of architectural heritage. Similarly, Obeso et al., [4] used convolutional neural network for classification of architectural styles of buildings in digital photographs of Mexican cultural heritage and stated that style identification with this technique can make a wide contribution in video description tasks, especially in automatic documentation of cultural heritage.

The classification process is used to automate some tasks at the architectural design stage. With the development of technology, the number of architectural elements increases as the building becomes more sophisticated in 3D models, and therefore, architects usually separate each geometry into semantically correct layers after the draft model is finished in order to model faster in the first stage of schematic drawings. The work of separating and labeling the geometries into individual layers is an ordinary task that does not require special knowledge. Yetis et al., [5] aimed to automate this work of architects and designers in order to reduce this workload and improve work performance. For this purpose, they applied and compared 5 machine learning models, logistic, k-nearest neighbors algorithm (KNN), support vector machines (SVM), naive nayes and decision tree, to label architectural elements in various parametric design environments (Rhinoceros, Grasshopper, Grasshopper Python and Grasshopper Python Remote).

The classification process can also be used in the architectural design process to correct situations that are impossible or difficult to change after the design process. Diker and Erkan [6], in their study, divided the window design efficiency of classrooms into 7 classes using fuzzy logic method, which is an artificial intelligence method. They stated that by using the developed model in the early design stage, it can enable the creation of window designs that provide sufficient visual comfort in classrooms by having pre-design knowledge. Some decisions made for the structural system during the architectural design process may need corrections in the future, and this causes losses in both time and cost. Bingöl et al., [7] created an Irregularity Control Assistant that can provide general information to architects about the compliance of structural system decisions with earthquake regulations by using deep learning and image processing methods to solve such problems at an early stage of architectural design. They stated that with the Irregularity Control Assistant they have created, it will enable correct decisions to be taken at the early stage of architectural design and reduce the corrections that may occur during the implementation project stage.

The development of hardware power that can process the increasing data enables the processing of visual data. This development will play an important role, especially in the processing of architectural data. Contrary to the previous studies, the images used in this study focus on the textures by going down more specifically, rather than the more general image (images based on function, design style and building type). Accordingly, in this study, the success of classifying satellite images with different textures of nature using deep neural networks was evaluated. It is expected that the use of image processing in the visuals of architectural structures will provide a different perspective to the detection and classification of materials, with the performance obtained because of the classification of satellite images with different properties of deep convolutional neural networks. Thus, various deep learning methods can be used to classify architectural designs, elements, and materials visually with computer vision techniques. In addition, a total of 4500 satellite images of cloudy (1125), desert (1125), green area (1125) and water (1125) were used to use a balanced data set for the accuracy of the model.

2. MACHINE LEARNING AND DEEP LEARNING

Machine learning is an application of artificial intelligence that provides computers the ability to learn and improve automatically from experience without explicitly programming it. In line with learning through experience, Mitchell [8] defines machine learning as follows: If the performance of a computer program on tasks at T (task), as measured by P (performance), increases with experience of E (experience), some task class learns from experience of E with respect to T and performance measure P. That's why machine learning focuses on the development of computer programs that can access data and use them to learn. Traditional programming logic focuses on obtaining output data from the input data, and therefore the output data to establish the appropriate program for the type of problem while using the software or by training machine learning machine with logic input and output data for the type of problem is obtained from the appropriate program or software [9]. In this direction, the primary purpose of machine learning is to enable computers to learn automatically without human intervention or assistance and to adjust actions accordingly. Machine learning allows them to make more accurate inferences based on their past experiences, now or in the future, and thus machines can help make the right decisions.

Deep learning is a subfield of machine learning concerned with algorithms inspired by the structure and function of the brain, called artificial neural networks. Multilayer deep neural networks are used in deep learning. Deep neural network algorithms are a multi-layered form of artificial neural networks developed by taking inspiration from the human brain. Deep neural networks are expressed as a neural network with an input layer, an output layer, and multiple hidden layers. In deep neural networks, the data learned at each layer constitutes the input data of the next layer, and thus a network structure is formed in which features are learned from the first layer to the last layer. Neurons in the structure of deep neural networks have weight values, bias and activation function. After the neurons are multiplied by the input value and the weights, an output value is obtained by adding the bias value. Various activation functions (tanh, sigmoid, relu) are used to control this output value obtained (to decide whether the neuron can be active or not).

3. METHODOLOGY

3.1. Deep Convolutional Neural Network (DCNN)

Deep convolutional neural networks contain 3 basic layers as convolution layer, pooling layer and fully connected layer, as well as some hyperparameters such as stride, pixel padding, filter (core), activation functions.

3.1.1. Convolution layer

It is the first layer used to extract different properties from an input image. The input image presented to this layer is treated as a matrix. In the layer, the properties of the image are obtained by applying a certain number of filters [10]. Filters are moved over the images and perform matrix multiplications. The values obtained from the multiplications are added and the resulting value is revealed.

3.1.2. Pooling layer

The image is transferred to the pooling layer after the convolution layer. The pooling layer uses the incoming data to create an output vector containing smaller and more meaningful information. A sizing matrix of the size specified in the pooling layer is applied. This sizing matrix is applied according to the step shift value on the image. Different pooling processes are available. In general, maximum pooling and average pooling are used. If the maximum values contained in the matrix are taken, the maximum pooling method is applied, or if the average of the values is taken, the average pooling method is applied. The main purpose of this layer is to reduce the number of parameters in the network [11]. As a result of this layer, there is a decrease in size, information loss occurs. The resulting loss of information is beneficial for the neural network, as it creates less computational load on the next network layers and prevents the system from memorizing [12, 13]. Reducing the parameters also provides incompatibility control in the network.

3.1.3. Fully connected layer

In convolutional neural network architectures, the flatten process is applied before this layer to use the matrices obtained from the convolution and pooling layers one after the other in the fully connected layer. As a result of the flattening process, the input data of the fully connected layer becomes ready. Operations are performed on coefficients from hidden layers. After the coefficient operations, the data are correlated with the selected density function and produce an output value [14]. The output layer of the network is the part where the result values are labeled. In this layer, neurons are connected to each subsequent neuron one-to-one, and therefore this layer is called the fully connected layer. The purpose of the fully connected layer is to use these high-level features to classify the input image into various classes based on the training dataset.

3.1.4. Classification layer

It is the last layer of the deep convolutional neural network model applied for classification problems. Since this layer is the layer where the classification process is performed, the number of output values is equal to the number of classes of the data used in the model. In the architecture of deep convolutional neural networks, the SoftMax classifier is generally used in this layer [15]. In this layer, the classifier predicts probability values between 0 and 1 for each class, and as a result, the class with the highest probability value becomes the class predicted by the model [16].

3.2. Performance Evaluation Criteria

It is necessary to evaluate the performance of the models to measure the success of the developed models or to decide whether the model is a good model. Different performance evaluation methods are used for classification in supervised learning. In this study, confusion matrix, accuracy, precision, recall (sensitivity) and F1-score ratios were used as performance evaluation criteria.

3.2.1. Confusion matrix

It is an analysis tool that shows the extent to which a classifier can classify different class labels. In other words, it is an n*n matrix that shows the number of correct and incorrect predictions made by comparing the results obtained by a classification model with the actual results. If the number of class labels in the data set is n, the matrix size is also formed in the form of n*n. The following four evaluations are used for classification estimates [17]:

I. True Positive (TP): They are positive class labels that have been correctly predicted by the model.
II. True Negative (TN): They are negative class labels that have been correctly predicted by the model.
III. False Positive (FP): They are positive class labels that have been incorrectly predicted by the model.
IV. False Negative (FN): They are negative class labels that have been incorrectly predicted by the model.

3.2.2. Accuracy

It is expressed as the ratio of correct predictions in the model to all predictions (Equation 1).

$$Accuracy = \frac{\text{True Positive} + \text{True Negative}}{\text{True Positive} + \text{True Negative} + \text{False Positive} + \text{False Negative}} \tag{1}$$

3.2.3. Precision

It is a success criterion that shows how many of all samples predicted as positive in the model are actually classified correctly (Equation 2).

$$Precision = \frac{\text{True Positive}}{\text{True Positive} + \text{False Positive}} \tag{2}$$

3.2.4. Recall (Sensitivity)

It is a criterion that shows how successfully positive situations are predicted (Equation 3).

$$Recall\ (Sensitivity) = \frac{\text{True Positive}}{\text{True Positive} + \text{False Negative}} \tag{3}$$

3.2.5. F1 score (F score)

Precision and recall (sensitivity) are the harmonic mean of the criteria (Equation 4).

$$F1\ score\ (F\ score) = 2 * \frac{\text{Precision} * \text{Recall (Sensitivity)}}{\text{Precision} + \text{Recall (Sensitivity)}} \tag{4}$$

3.3. Developed Model

In the model, the data set shared as “Satellite Image Classification Dataset-RSI-CB256” on the “Kaggle” platform was used. A total of 5631 satellite images of cloudy (1500), desert (1131), green area (1500) and water (1500) mixed from sensors and google map snapshot are available in this data set. However, 1125 images belonging to each class were used in order to use a balanced data set (Figure 1).

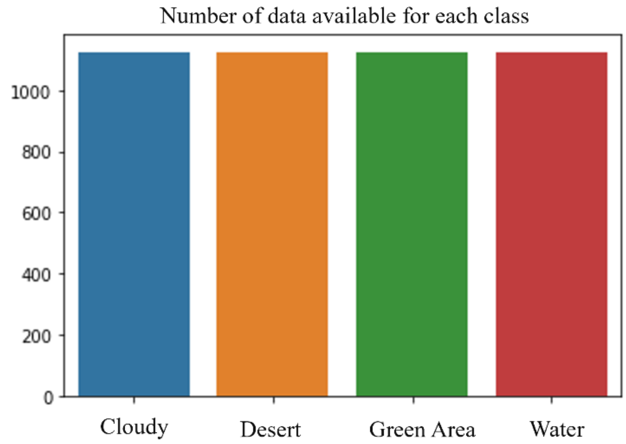

Figure 1. Number of data available for each class

Some sample images of the classes from the data set used are shown in Figure 2.

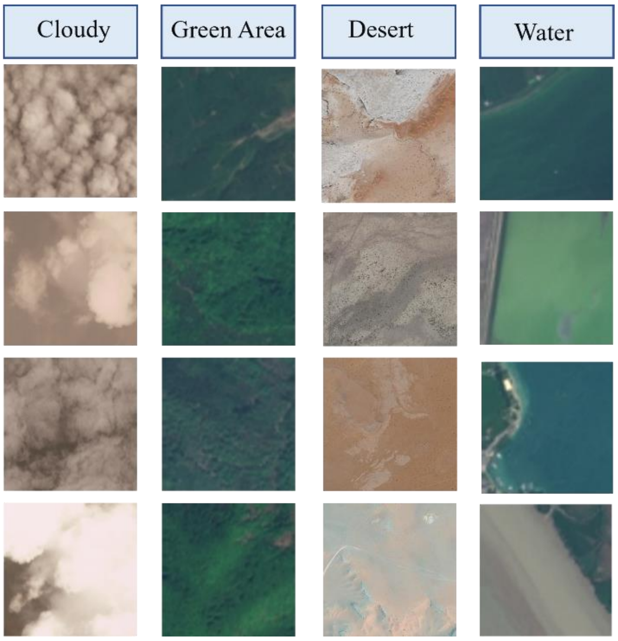

Figure 2. Examples of data sets of satellite images used

The design of the developed deep convolutional neural networks consists of 4 double convolution layers and a maximum pooling layer repeated 4 times, followed by a flattening layer and 4 densely connected layers. The core size is 3×3 for all convolutional layers, and the core size is 2×2 for all maximum pooling layers. ReLU (Rectified Linear Unit) activation function is used as an activation function in hidden layers. Since the output layer has 4 different classes, the SoftMax function is used as the activation function. For the developed deep convolutional neural network model, the Google Colaboratory program, which is offered free of charge by Google, was used with the Python programming language. The general architecture of the developed deep convolutional neural network model is shown in Figure 3.

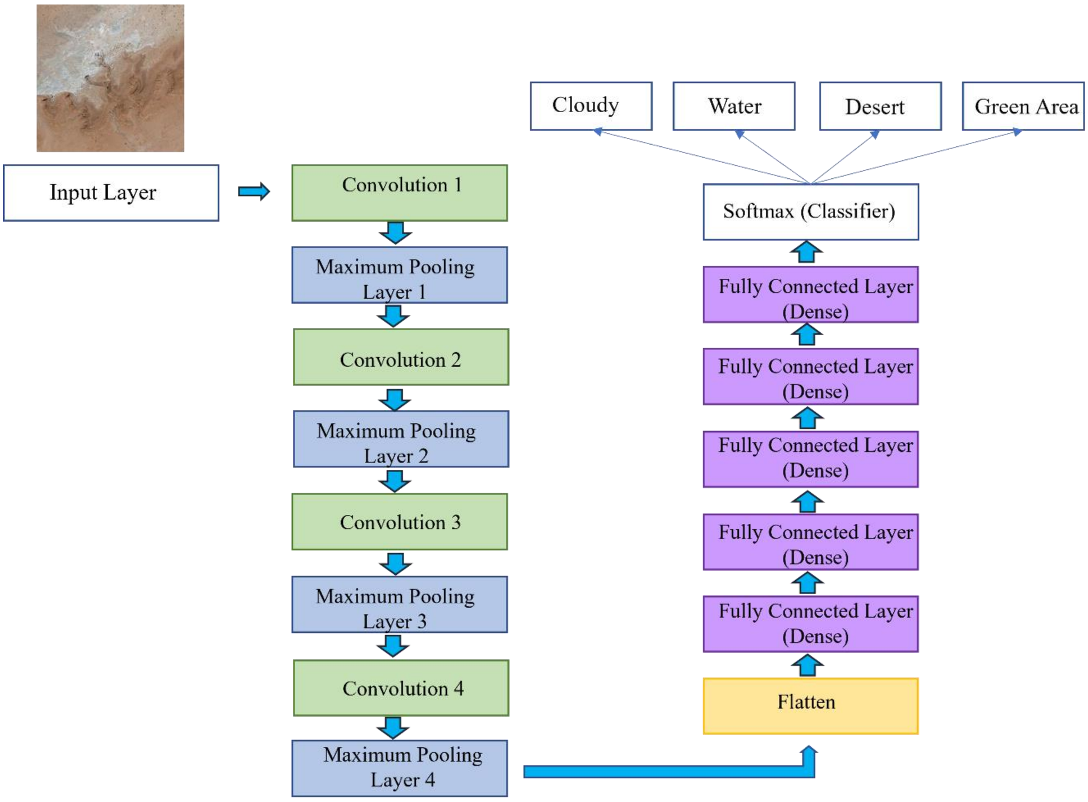

Figure 3. The developed Deep Convolutional Neural Network architecture

3.4. Results of the Model

75% of the dataset was used for training, 15% for testing, and the remaining 15% for validation. In the training of the developed model, 100 epochs, 0.0001 learning rate and Adam optimization algorithm were used. Accuracy and loss rates in training and validation during the epochs are shown in Figure 4-5.

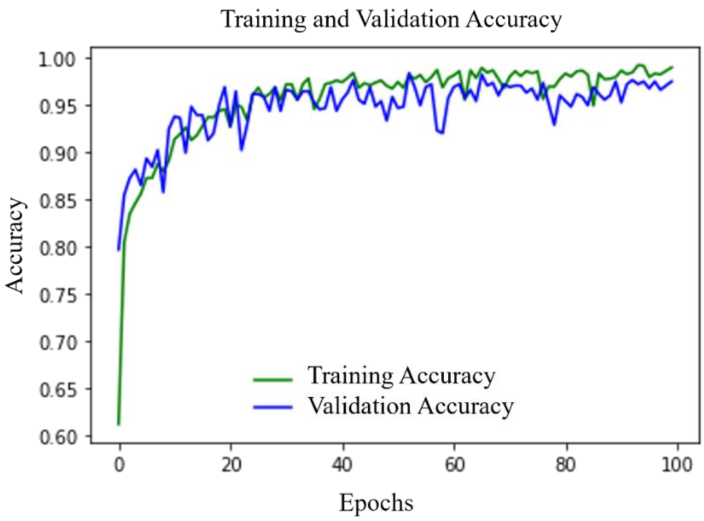

Figure 4. Training and validation accuracy graph obtained from the developed model

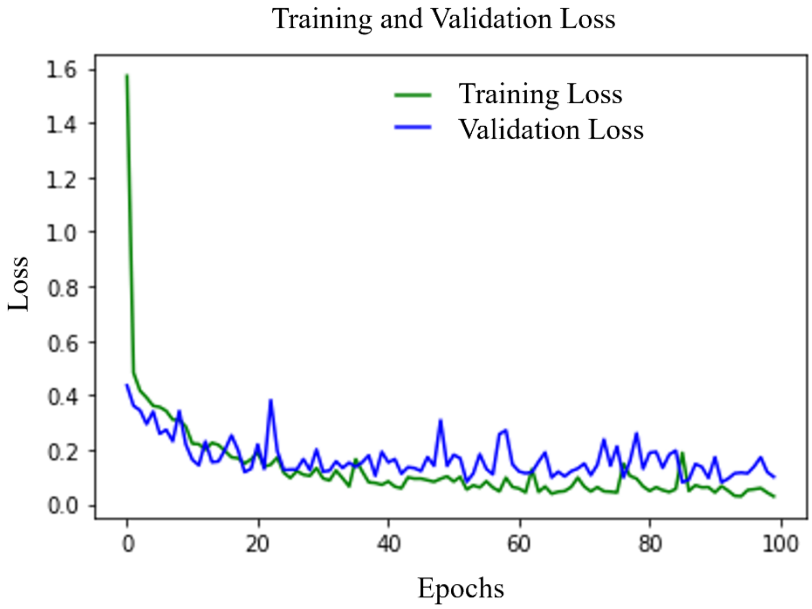

Figure 5. Training and validation loss graph obtained from the developed model

The performance of the developed deep convolutional neural network model was performed using different evaluation criteria. The estimation efficiency of the model was evaluated using four different performance evaluation criteria, namely accuracy, precision, recall (sensitivity) and F1-score. These values are calculated based on confusion matrices for each class. The confusion matrix obtained from the developed model is shown in Figure 6 and the results of the performance criteria evaluated according to this matrix are shown in Table 1.

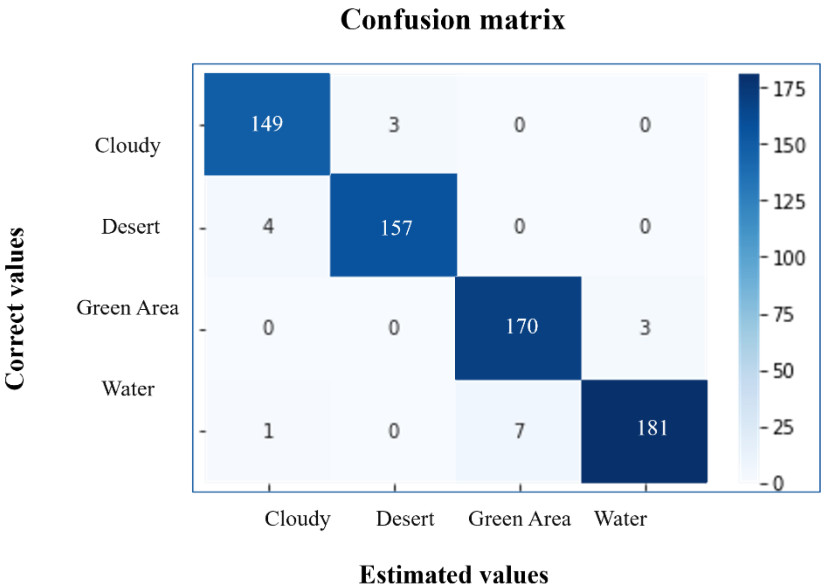

Figure 6. The confusion matrix obtained from the developed model

Table 1. Performance results of the developed model

	Cloudy	Desert	Green area	Water
Accuracy	0.97	0.98	0.96	0.98
Precision	0.97	0.98	0.96	0.98
Recall (Sensitivity)	0.98	0.98	0.98	0.96
F1 score (F score)	0.97	0.98	0.97	0.97

4. CONCLUSIONS AND RECOMMENDATIONS

With the continuous development and progress of technology, machine learning algorithms, which are an artificial intelligence application belonging to the sub-branch of computer science, are used to recognize, analyze, learn from these data, and make decisions based on what they have learned. One of the machine learning methods, especially with the increase in hardware power, the processing of visual data with deep learning can facilitate the acquisition of appropriate and useful data with shape recognition among many data, especially in the information collection stage in the architectural design process. In addition, it can help to make more accurate decisions by obtaining more comprehensive information (obtaining information that may be missed in manual searches). While inconsistent and incorrect results can be obtained with traditional methods, the error rate can be reduced using machine learning methods.

As a result of the model developed with deep convolutional neural networks, satellite images were successfully classified. Even if the desert and cloudy images are like each other, all but 8 images were classified correctly in the test data (675 images). Only one of these 8 images is classified as water. Similarly, although the images of the green area and the water are similar, all images were classified correctly, except for 10 images. This situation has shown that successful results can be obtained in the visual processing of architectural structures. In addition, unlike other studies, achieving this success in textures has shown that it can be successful in detecting, analyzing, and classifying architectural materials found in the visuals of architectural structures. Learning the distinctive features of data for classification in machine learning also explains design differences and similarities, and thus reveals hidden relationships in designs. This will allow architects and designers to make more creative and original designs. In addition to these, the ability to process visual data can facilitate the acquisition of appropriate and useful data with shape recognition among many data, especially during the information collection stage in the architectural design process, and thus, it will help to take more accurate decisions by obtaining more comprehensive information.

The classification process can be used to automate some work during the architectural design stage. For example, with the development of technology, the number of architectural elements increases as the building becomes sophisticated in 3D modeling, and therefore architects usually divide each geometry into semantically correct layers after the draft model is finished to model faster in the first stage of schematic drawings. By automating some monotonous work in the architectural design process with classification, it can reduce the workload of architects and designers and improve working performance. It can also be used for archiving increasing data (architectural artifacts, styles of buildings, etc.) with classification. This reduces the workload in digital documentation and contributes to its automation. With the model used in this study, it will be possible to classify, separate and even determine the distinguishing features of architectural elements. The increase in the number of architectural elements, the diversity of construction systems together with the developing technology reveals the importance of classification processes. In the model developed with the study, it is foreseen that façade applications, material classification and even data archiving can be done even by being inspired by the satellite images that are successfully classified. In addition, it is thought that additional design parameters may arise with the acquisition of data that cannot be obtained with manual data, which will provide designers with different perspectives.

CONFLICT OF INTEREST

The author(s) stated that there are no conflicts of interest regarding the publication of this article.

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IMPROVING EXISTING HOUSING STOCKS A MODEL WITH ARTIFICIAL SMART SUPPORT

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ABSTRACT

Habitable housing and a healthy environment are a fundamental human right. In ensuring that existing housing stocks are re-acquired with artificial intelligence support, in making them healthy and sustainable, the development of a support intelligent system is the main topic of this study. The improvement of what is present provides a holistic benefit that has a return in economic, social, cultural and environmental contexts. It is increasingly important to take advantage of technology to make predictions and assessments with effective policies as well as effective strategies, algorithms, software development, and simulation in improvement projects. The goal is to preserve the resources and energy we have, reduce waste production to zero, reduce carbon footprint, and use the smart model supported by artificial intelligence in this study. Demolition and rebuilding should only be considered as the last resort, as the growth of environmental, cultural, waste areas, and waste resources and energy waste. Improving robust and functional buildings without demolishing them, adapting structures with cultural value to current technology, ensuring sustainability with a smart system can be achieved. In this study, it is aimed at achieving a 'Smart Model', which is supported by artificial intelligence, which is designed in light of examples around the world to evolve existing housing stocks with high environmental impact and resource utilization, into buildings with technology-appropriate equipment that have sustainable properties for resource use.

Keywords: Existing housing stock, Intelligent model with artificial intelligence, Improvement, Technology in architecture, Sustainability

1. INTRODUCTION

The main problem covered in the study is to address environmental, social and economic problems created by existing housing stocks, and to ensure that these structures can be dealt with with evolving technology and technological systems. The aim of this is to reduce environmental impact in the dwellings, increase efficiency in resource use, equip and improve the necessary technological systems and transform them into modern dwellings. In line with this goal, the '***Artificial Smart Supported Model Proposal***' is designed to create alternative resources for the dwellings, it has been prepared to establish which types of improvements can be made in the headings identified and to ensure that these improvements are made in the growing number of residential stocks, using artificial intelligence technology, and that the system will use time effectively to learn and solve the next housing problem through these types, to prepare the ground and ensure that the system remains up-to-date.

The changes that started with the Industrial Revolution in the world changed the living conditions, paving the way for new demands. Changing living conditions have also shaped the need for shelter. Housing in people's lives has come to a point, and in certain periods, housing has become the goals of individuals. In the face of this growing demand, housing construction has gained momentum and in line with the advancement of technology and construction techniques, the silhouettes of almost all cities have begun to change.

He has earned his share of these changes in our country. Development of ready-made concrete technology, acceleration of material supply, easy access to workforce, etc. the reasons have caused the

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number of housing to increase day by day. In addition to this situation, economic incentives and economic income expected from the sale of housing have resulted in some changes in the production industry's goal. As a result of these changes, it is possible to make stock of housing that overcomes the demand, plan housing similar to each individual, and start producing foam from the context of the dwellings.

Table 1. Iskan Information received in Turkey between 2018-2020 [1]

	2020	2019	2018
Number of Buildings	53.986	70.529	88.609
Surface Measurement (m²)	86.198.564	111.645.002	120.100.622
Number of Apartments	423.733	545.006	614.161

Table-1 of projects certified by LEED, including 2020, despite housing data included in Table-1, is 428 according to World Green Building Council (WGBC) data [2].

As a result of these changes, the use of resources in housing has accelerated, resulting in pressure and stress on resources at a certain stage. The reduced resources and increased resource use are not only changing human living conditions, but some of the important vital problems that come up in a variety of ways -- ecological changes, decreasing the number of species of life, etc.

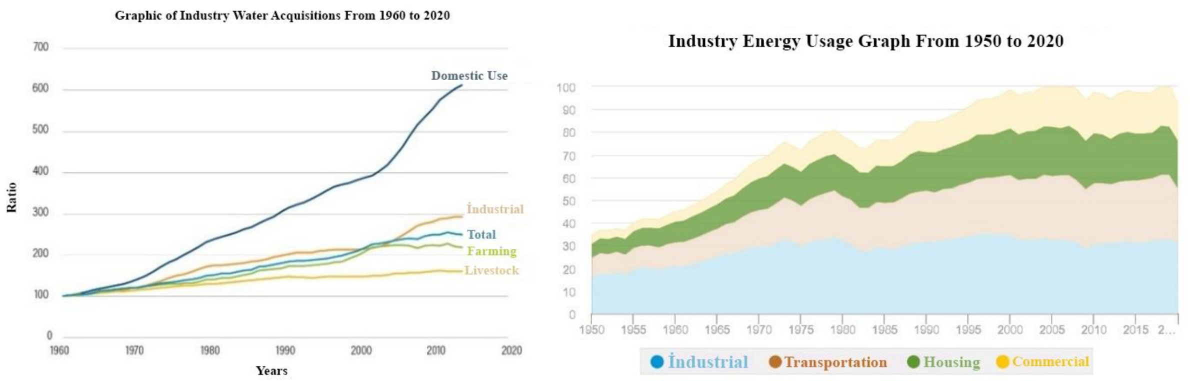

Figure 1. Housing Resource consumption Left Panel water Acquisition, right Panel Energy use [3]

The fact that the activities and forms of the past continue in the same way without meeting the requirements of today's world is one of the key factors at the heart of these issues. The development of technology and the rise of quality standards of life has brought a great momentum especially to the construction and construction industry. The rate of use of resources, nature and its resources, in line with the number of households and the number of housing, has been under pressure and stress by putting this momentum behind it. At this point, concepts that can respond to the age by using the support of developing technology, which have systems that can improve resource utilization, must be the main target in the construction industry, and existing housing stocks must be integrated into that goal.

2. FOR A BETTER FUTURE, SOLVING TECHNOLOGICAL DEVELOPMENTS IN ARCHITECTURE

It is undoubtedly sustainable, one of the concepts that has emerged in recent years, especially against changing world conditions and ecological conditions. Sustainability is defined as the definition of meeting today's needs without disclaimer of the ability to meet the needs of the next generation in development and progress [4]. One of the key points in this definition is that it reveals a wide range of situations without pointing to a specific area. In this way, sustainability can be described as a universal concept.

The main idea in the architectural design dimension of sustainability minimizes the negative side of existing building systems, putting environmental factors in focus for the product with features that internalize the natural one [5]. This is the case of the objectives of sustainable architecture [6]:

- Maximize human comfort
- Design for change
- Protection of the natural one
- Reduced costs and increased efficiency.

Sustainable architecture integrates technology and human goals to achieve these goals. The International Council of structures defines sustainable architecture as a concept based on resource efficiency, creating healthy space, which is the lowest in natural/artificial environmental incompatibility [7], and considers it a parameter that contributes technological developments to the process in achieving this situation. This also combines the objectives of the Artificial Intelligence-supported Model proposal with the sustainability goals of architecture. The Intelligent Model proposal with artificial intelligence will provide a system that will support sustainable architecture through an improvement method in existing housing stocks, and will develop this support on the technology base.

Technology systems are often present as systems that make human life easier in many areas that depend on world development in a short period of time. "How can technology help sustainable architecture?" in its relationship with sustainability, which is an important concept in the building sector, particularly in the solution of problems in the world he can be asked a question.

Technology systems and sustainable buildings are basically [8]:

- Provides sustainable requirements that represent continuous adaptation with the technology systems it has.
- Supports sustainability by increasing efficiency in resource utilization through its hosted automation and technological systems.
- The flexibility of the overall structure of the system and the concept of architectural design and sustainability.

In general, the concept of technology offers healthy and comfortable locations to help people and their lives through the social, economic, environmental components of sustainability. Therefore, they support the concept of sustainability from the design of the structure to the destruction of the structure, which creates basat systems in achieving the basic concept of sustainability.

3. FOR A BETTER FUTURE, KAPFENBERG HOUSING BLOCK EXAMPLE

There are many households in Europe that offer sustainable housing solutions, especially with the necessary measures after the war. One of these examples is the housing block in Steinmark, Austria.

Figure 2. Kapfenberh Structure Left Panel previous carpet - right Panel New carpet [9]

The existing residential block has been improved by refreshing it with a number of systems to be able to use energy efficiently and improve the quality of life in locations. Improvements to this purpose [10]:

- Energy Rehabilitation
- Material Renewals
- Improved Location Quality
- The Solution of Accessibility issues is collected in the headings.

With energy rehabilitation in the structure, it is aimed at significantly reducing energy consumption with the help of today's technology. 80% of heating was achieved by renewable energy in CO2 and 80% of the heating system.

A contemporary solution has been developed for the construction to achieve renewable energy. The steel construction, integrated outside the structure, is equipped with solar panels to provide renewable energy. The resulting solar power works by feeding a layer of thermal storage tank through a feeding system that fills the storage units in each circle.

In addition, a new prefabricated facade has been developed for the existing facade for construction material. With this prefabricated front, the service channels of the entire building have also provided the advantage of directing them behind the outer shell.

For improved location quality, sun control is provided by adding a porch to the east-facing facade of the building. In addition, new ventilation systems, expanding living spaces and adding balconies to each apartment are aimed at improving quality of life. In addition, improvements have been made by offering flexible solutions within the structure for disabled and wheelchair circulation.

In general, the structure has developed different solutions to improve vital quality and contributes to the sustainable environment. With these solutions in the structure, PlusEnergy in Austria won the renewal award.

4. SMART MODEL WITH ARTIFICIAL INTELLIGENCE IN TRANSITION FOR A BETTER FUTURE

The reflections of the development of technology in the world have affected the construction industry as well as any industry. The shortening of time in construction has caused the increased demand in our country and the number of housing in cities to increase in a short period of time, and this has started to create housing stocks, combined with economic expectations. The disintegration in the context of these structures has influenced the process of resource use by establishing the basis for other problems. The proliferation of such structures has caused similar problems due to the similar similarity of existing housing stocks.

In this part of the study, the aim is to reduce the environmental impact of these existing housing stocks, promote renewable resource use, improve spatial quality and remain up-to-date with the concept of artificial intelligence [11]:

- **Intelligent Systems**
- **Energy Management**
- **Water Management**
- **Material Management**
- **Biological Management**

To ensure that these structures are ***'unbroken'*** by re-evaluating them with their headers.

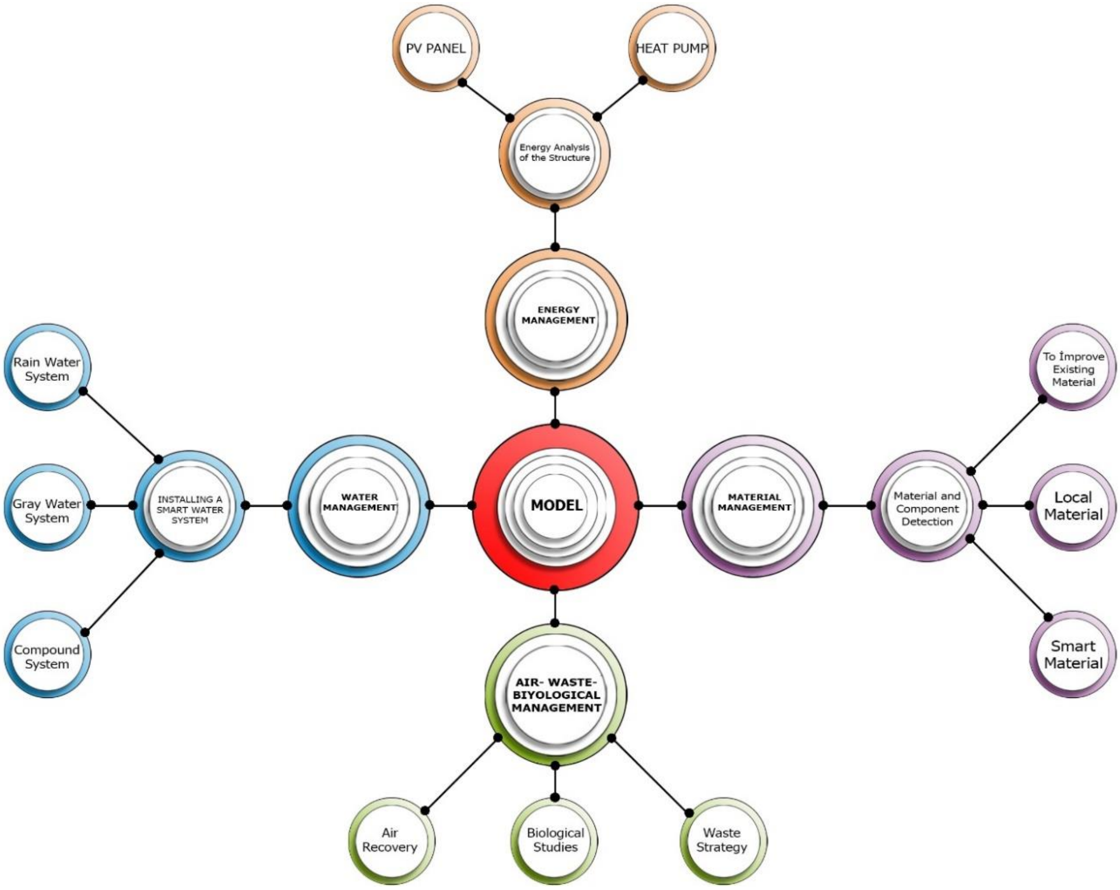

Figure 3. General strand of the recommended Smart Model during the transition (created by the Author).

The top headers and a brief summary are provided in Figure 5, which provides an overview of improvements to existing housing stock.

- ***Energy Management;*** the energy needed in the dwellings in general is intended for electrical and heating/cooling. In the fulfillment of these energies, the 'PV Panel and earth-welded heat pump' are two current concepts. With evolving and changing technology, the effort to improve the efficiency of these two alternative sources is crucial to renewable energy resources in the construction industry.

- ***Water Management;*** the increasing water stress on countries in parallel with the developments in the world has made it clear. The United Nations water Development Council [12] has shown our country that water stress will be intense in its recent release. This is a clear indication that our strategy should be reorganized in the dwellings. Therefore, the aim of this administration is to reduce water exposure by creating alternative resources by adding ‘rainwater systems and gray water systems’. In addition, the work carried out is expected to reduce the need for water by %94 by using these two systems together [13].
- ***The Biological Environment Management***, aims to reduce the environmental impact of structures and improve the quality of life. "Green front, green roof, etc." in structures the use of ‘green dividing elements’ in the interior will contribute to the development of both the spatial quality and the healthy environment.
- ***Material Management***, aims to reduce the environmental impact of the material used, improve the impact on human health, and promote the structure ‘local material and natural material’.
- ***The concept of AI***, will be with ‘artificial intelligence technology’ in ensuring system continuity and the model can improve itself by rebuilding itself over the course of the process. The system's data inputs will be the main component of the artificial intelligence technology system to evaluate this data and to develop solutions that match this data, but will also be aimed at improving efficiency in future issues. With the concept of artificial intelligence technology (human-in-loop) [14], it will be aimed at making the system more stable, bringing the system to the desired accuracy, including the human into the loop, and using the human efficiently.

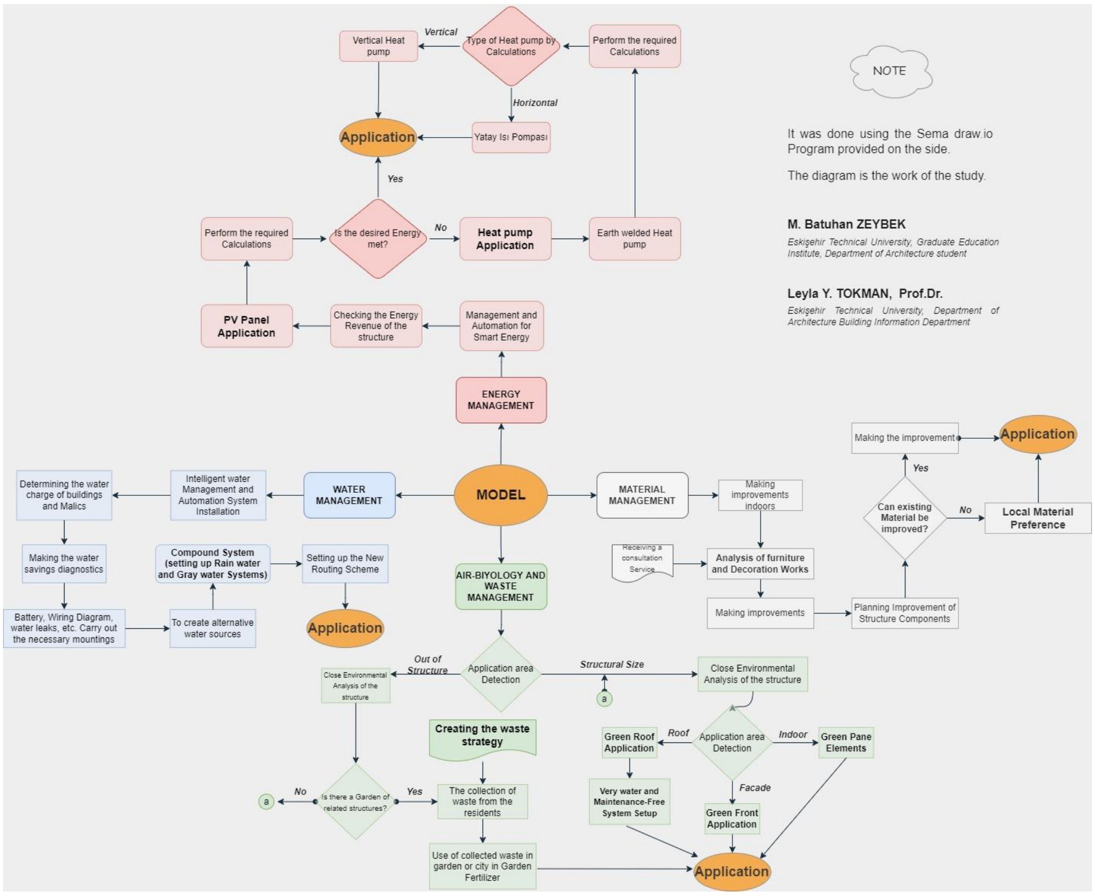

Figure 4. Recommended Artificial Smart supported Model proposal (created by the Author)

As a result, reducing the environmental impact of existing housing stocks and making improvements to certain headlines of these structures will help save cities before they become construction sites, and then regain them without adding extra burden to the country's economy. This system and model have aimed at a long-term perspective where structures improve in the short term, where cities improve.

5. RESULT

The developments in the world that the Industrial Revolution and its foundations have defined new standards of living for humans. By adding the increasing population in the world to these developments, the consumption of existing resources has increased and has a negative impact on these resources. One of the largest stakeholders in increased resource consumption is the construction industry. The production activities that continued with the past-term systems have often overlooked technological systems, creating a natural pressure on which it has reduced resource utilization efficiency.

The expectations of the dwellings must change. The existing structures should now be designed to be able to use technological systems actively, and the existing structures should be expected to participate in this change. The parameters set by the American Green Building Council in the ‘Smart Model with Artificial Intelligence’ proposal prepared for this purpose [15]:

- **Smart Systems**
- **Energy Management**
- **Water Management**
- **Material Management**
- The basic diagram and objectives of the system are prepared using **Biological Environment Management.**

In addition to these goals, the concept of artificial intelligence, which is effectively integrated into all systems in the changing and evolving world, is one of the key components of the study. In general, the artificial intelligence system will ensure that the model remains up-to-date in terms of ‘using it to automate jobs that require human intelligence and be able to do much superior tasks and calculations than the human brain can afford’ [16].

It aims to ‘protect the natural one, provide sustainable quality of existing structures using artificial intelligence technology, improve quality of life for residents, improve economic direction and manage it’ through existing housing stocks with an intelligent model built with artificial intelligence system (human-in-loop).

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ARCHITECTURAL DESIGN WITH GENERATIVE ALGORITHM AND VIDEO PROJECTION MAPPING

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ABSTRACT

The innovative and creative approach that is produced for architectural design problems involves quite complex stages. In architectural design, the designer's approach and numerical data make the design process a multi-layered structure. The integration of parametric modeling programs and generative algorithms makes it easy to carry out multi-layered design processes. Generative systems defined through generative algorithms enable conceptual approaches, various geometrical constructs, and different forms to be created in digital environments in solving design problems. The creation of the generative algorithm of the design eliminates the restrictive role of modeling software in the architectural design. The designer gets the opportunity to create every parameter and design criteria specific to his approach.

In this study, our aim is to develop a generative algorithm in a computer environment by using the principles of fractal geometry function. The generative system creates by overlaying the developed generative algorithm with the environmental factor parameters. In this system proposal, the goal is to produce various facade design proposals by coding the algorithm fractal functions and to make use of the visualization of various potentials of the generative algorithm in parametric facade proposals. Video projection mapping method is chosen to discuss the functionality of the parameters in the proposed generative system of the developed generative algorithm. Computation of the transformation relating consecutive image frames is an essential operation in video mapping. In this context, the design created with the generative system is reflected on a real scale medium , specifically a column in this study, and various image frames letting new design proposals produced by the algorithm were evaluated. In concluding rmarks, the advantages of architectural designs modeled by coding with the generative algorithm compared to the algorithms obtained directly with the software are discussed.

Keywords: Generative Systems, Algorithm Design, Generative Fractal Algorithm, Video Projection, 3D Mapping

1. INTRODUCTION

Architectural design tools have changed and transformed over time with the developing technology. Thus, architects integrated computer-aided approaches into architectural designs. Modeling programs and software interfaces facilitate design processes, but also bring limitations in mental production processes. Sometimes design ideas cannot be visualized directly through these programs, so we have to use conventional design tools. However, this situation complicates the calculations in the digital design processes. If the designer codes the generative algorithm of his design initially, software becomes a developing tool. In the studies conducted with architecture students, they observed the limitations of the software interfaces in the individual works of the students. However, they also evaluated that the students who knew how to code their algorithm could directly transfer their designs to the digital environment [1].

The thinking process and logical operation in a hand-drawn line based on the design coincide with the algorithm-based line. Architectural designs with algorithms allow parameters to self-organize [2]. The situations that are unpredicted in the design processes can be formulated by manually changing

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parameters or running algorithms iteratively. In addition to that, relationships that the designer cannot predict can also appear by manually changing parameters or by running algorithms iteratively [3]. Algorithms are essentially mere form of expression of the thinking process [4]. Through this form of expression, seminal parametric designs occur. Designing with algorithms is a new design skill as well as a new way of discovering the potential of design [5]. With this new design skill, the designer can formulate his own geometric algorithm. Thus, geometric algorithms remove the boundaries between modeling software and the designer [6].

Parametric designs depends on algorithms formed by the combination of different parameters and consist of a combination of algorithms that allow variations [7]. On the other hand, algorithms involve a certain number of steps in reaching possible solutions to the defined problem [8]. Modeling of parametric designs depends on the creation of algorithms. The parametric design not only allows for the diversified geometric organizations but also for the different variations [9] and complex forms (Schumacher, 2009). It provides flexibility in the design process as geometric relationships can be clearly defined in the parametric design process [11]. It is also necessary to determine the constraints in the design processes for constructed parametric geometries and to create the parameters in a way that can diversify the design [12]. Parameters provide a variety of solutions as they allow the development and numerical control of geometries in the design [13]. It enables the identification and control of the relationships among the elements [14] and creates meaningful tectonic potentials for the elements [15]. Thus, design schemes that are not able with traditional methods, appear in the second and third dimension through algorithms. Creating algorithms is no longer the domain of a particular discipline. This method is open to architectural design, and expressing architectural designs in the form of algorithms offers the opportunity to collaborate with other study disciplines [16].

Fractal geometries provide various design potentials especially when working with algorithms. Fractals consist of compression, rotation, and nonlinear transformations of a given geometry. Fractal geometries provide the relationship between nature's complexity and architecture. This aspect of fractal geometry facilitates prototyping in surface designs in architecture [17]. Forms produced with fractal geometry turn into complex structures [18]. Functions of complex structures can be reduced to fractal functions and thus they are converted into generative algorithms [19]. Fractals exposes a form of grammar that facilitates the assimilation of syntactic information in architectural designs diversified with a generative algorithm [20]. Fractal geometries are qualified to design aids with fewer rules, more repetitions, and more formal similarity than other shape grammars [21]. Complex system designs in architecture, which cannot be created with traditional methods, are made through generative algorithms [22]. By this means, it is possible to design complex systems providing numerical consistency.

Visualization of algorithm-based complex designs at real scale provides the opportunity to experience the design. Architectural design can be transmitted in the second and third dimension in one-to-one scale with the video projection mapping method. This method proposes projection of a created video on an architectural surface or communication of the video with an architectural design [23]. The use of video projection mapping in the architectural field is a method that includes the subject as the designer or user as a viewer in the visual projected element. This method is also usable in the design and concept stages of the projects [24].

The integration of designs with video projection mapping method, it is possible to experience digital models in the second and third dimension. This methodology ensures that the images integrated in the desired geometric form are transferred on to the real scaled design surfaces (Figure 1). In this study, the actual dimensions of the design become one of the parameters of the generative algorithm. In order to discuss the effect of the parameters in the generative algorithm, the design coded with the generative algorithm prompt is projected in real scale with video projection mapping.

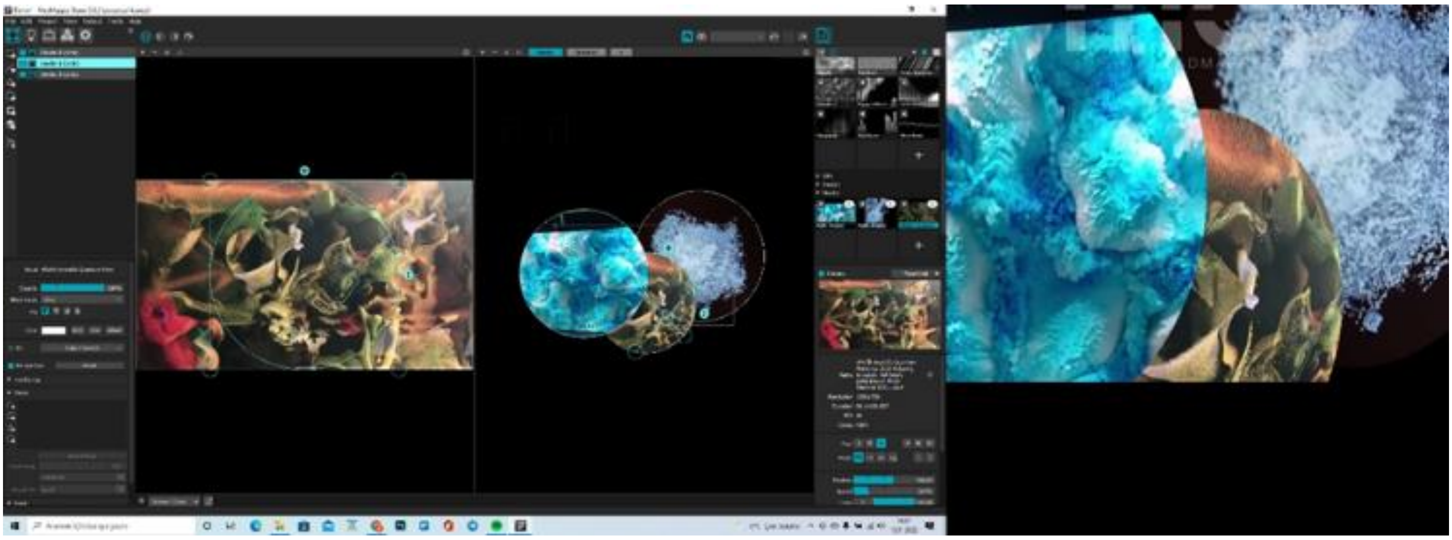


Figure 1: Madmapper video projection mapping working with curvilinear geometries [25].

In this study, we used fractal function in the generative algorithm system developed within the scope of the study. The selection of fractal function enables to provide the control of the point and vector positions of the geometry after the third iteration, which is not possible without computer. After the third iteration, vectors and point coordinates in space geometry become incalculable. However, the generative system, which consists of the combination of the generative algorithm with other parameters, can produce this information regularly. Thus, a generative algorithm based on the features of fractal geometry on projected surface design as in architectural parametric facade designs is created, benefiting from its continuity. The syntactic scheme of the generative algorithm is coded in the Python scripting language accessible from Grasshopper interface. The visualization process of the syntactic language is generated by the Rhino interface. The design-specific coding of the generative algorithm provides guidance and varied features in the design. This approach, which shows the topological and geometric aspects of the architectural pattern, has been integrated and presented as a generative system in which various parameters managed. The proposed generative system algorithm is supposed to discuss the various potentials of parametric facade designs in the early design phases.

2. GENERATIVE SYSTEM DESIGN AND METOD

In order to design the generative fractal algorithm system through the object-oriented algorithm, a writing language is developed that consisted of three main steps as expressed in the flowchart (Figure 2). These steps are respectively;
• Designing the generative fractal algorithm
• Determination of the start and targets of the parameters
• Visualization of the design
Once the concept design is created the system automates the other stages of the flowchart. For this reason, only the initial function belongs to the designer. In this direction, the coded algorithm in the Rhino-Grasshopper environment through the Python software language works as a generative system in other stages. With the automatic iterative operation of the algorithm, the visualization is provided in Rhino and relatively the design is diversified iteratively in the process by producing various output values.

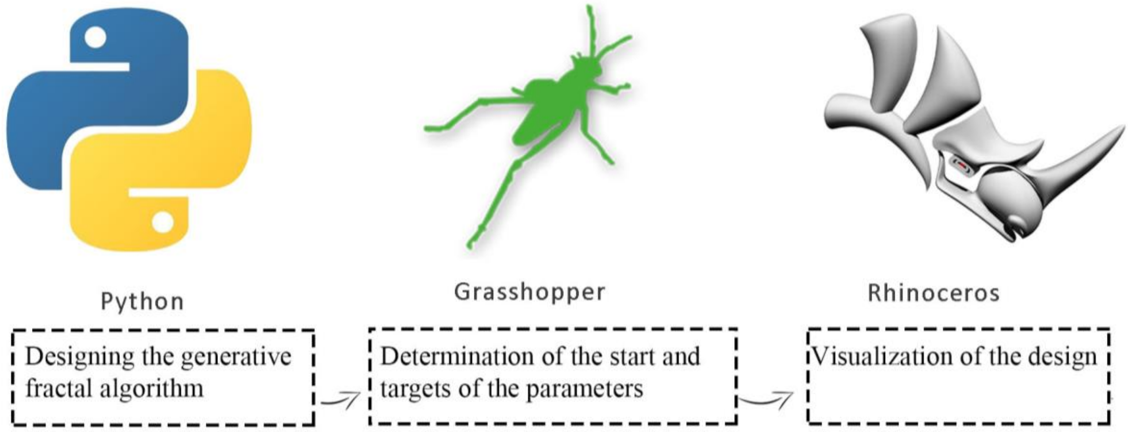


Figure 2. Flow chart summarizing the sequence of use of the software and coding language used in the study process. (Prepared by the authors.)

The flowchart of the algorithm is defined to design a generative algorithm system (Figure 3). During the coding process of the algorithm, the actual dimensions of the column selected as the sample projection surface are measured at the first stage. The dimensions of two consecutive surfaces of the column are also measured, respectively. According to the measurement results, the algorithm defines the three-dimensional geometry of the column. Thus, the changes in the designs suggested by the algorithm are observed in the real size changes with video projection mapping. The algorithm first calculates the coordinates of each vertex to divide the object surfaces. These coordinates are grouped into lists. The values in the list are associated with parameters named P_up, P_down, Level. This parametric change creates the generative fractal loop associated with the diversification of coordinates. In each production, the coordinates are calculated and listed by the algorithm. In order to generate the fractal loop iteratively, the data in the new list is redefined as the variables of the fractal function, and new surfaces are created by the generative operation of the algorithm. The defined surfaces are automatically moved axially by the algorithm. Various suggestions are obtained at each stage during this automatically moving process. During the iterative generation of the algorithm, new points, position vectors, surfaces are defined on the design geometry. The position of each new geometry in the spatial geometry is coded by the algorithm as a data list. In addition, the number of fractal units belonging to each generative design is determined in the data list. In this way, the spatial coordinates inform about the geometry obtained by the generative algorithm. In order to generate the fractal loop iteratively, the data in the new list is redefined as the variables of the fractal function and new surfaces are created by the generative operation of the algorithm.

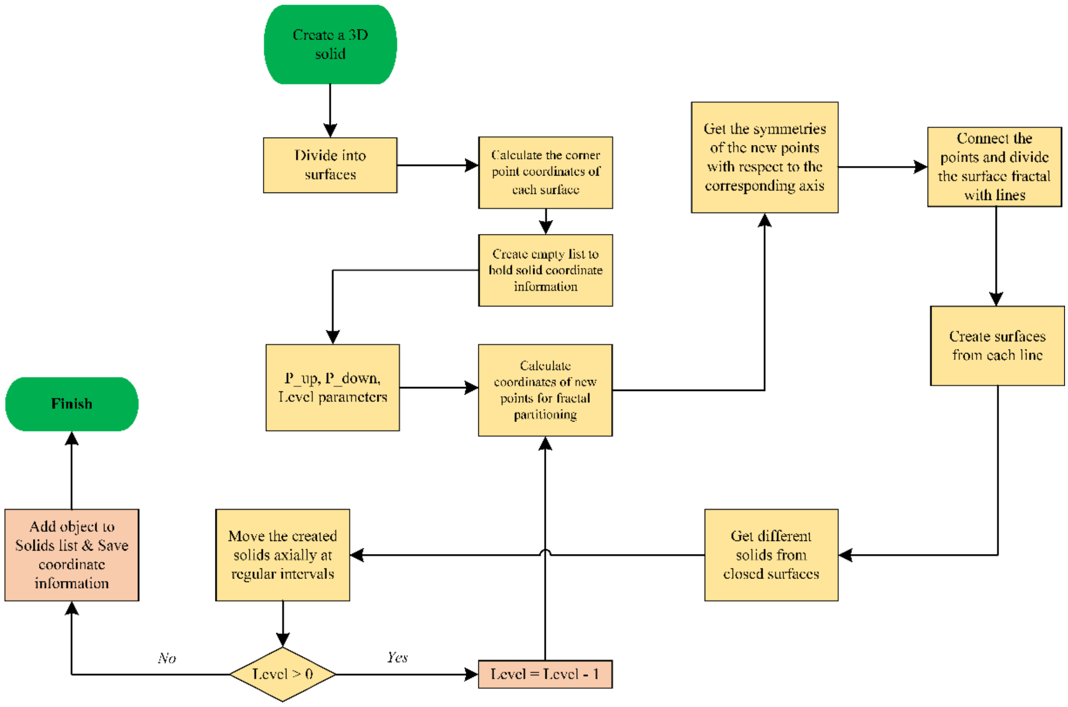


Figure 3. Python algorithm flowchart (Prepared by the authors.)

3. FINDINGS

In this study, a generative fractal algorithm is designed, which is coded through an object-oriented software language. With this algorithm, a generative system has been defined with the aim of diversified facade designs. Within the scope of the study, iterative production of the concept design by the algorithm on the surface of the column, which was determined as the projected surface, gives us as a sample scenario. The fractal algorithm coded in the object-oriented Python programming language in the Grasshopper interface provides various parameters added to the algorithm in which the numerical ranges can be changed from within Grasshopper. It has been observed that defining the parameters both in the algorithm and in the Grasshopper interface is effective in diversifying the design (Figure 4).

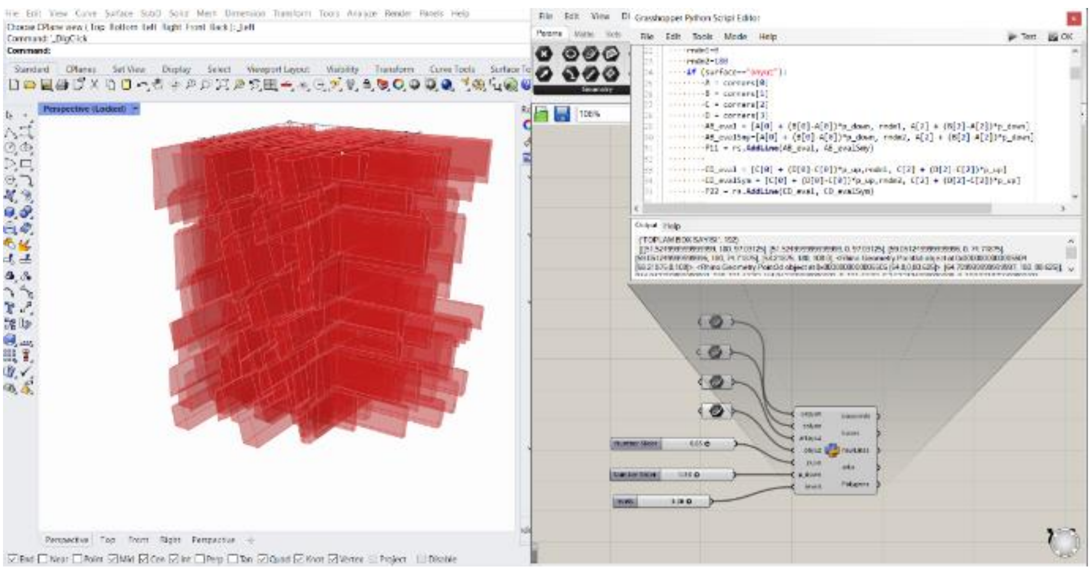


Figure 4. Python-based generative Grasshopper algorithm (Prepared by the Authors)

In the process of designing the fractal function algorithm firstly, the algorithm was coded to give outputs in the second dimension. Various outputs are obtained with the automatic generation of the fractal. In the process of obtaining the outputs of the fractal geometry algorithm, first it makes a random selection from the two parallel sides of the rectangle. Then it defines a line by connecting two randomly chosen points over the selected parallel edges. Respectively, two more lines are defined by selecting two more points on the line created in the previous step by defining points from the mutually parallel sides that were not selected. From this stage onwards, the fractal geometric loop becomes visually perceptible (Figure 5).

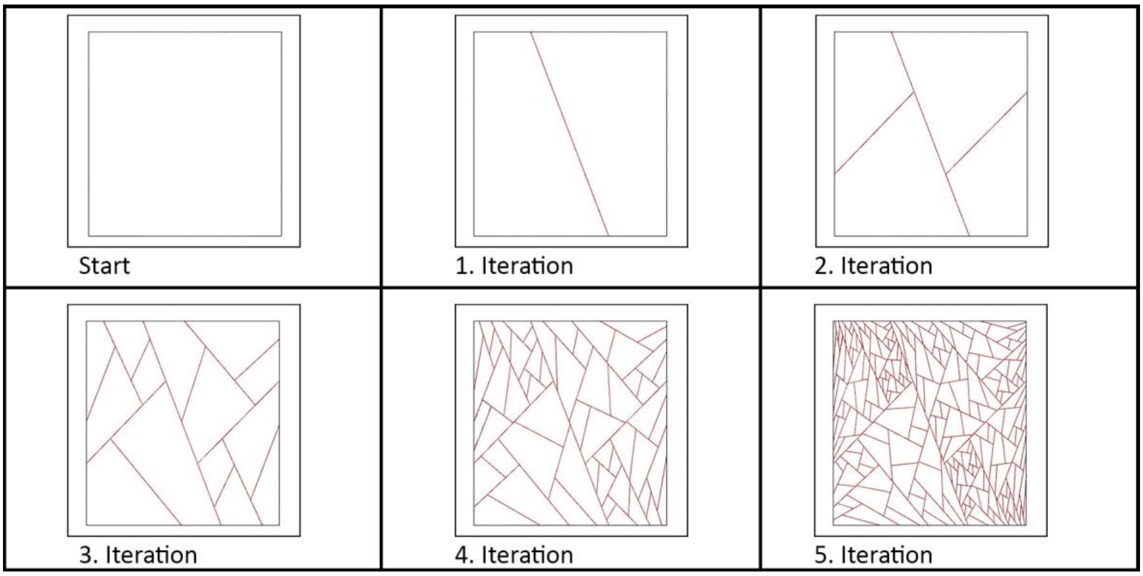


Figure 5. Second dimension outputs of the generative fractal algorithm designed via Python (Prepared by the Authors)

While the algorithmic loop continues, it also recognizes and divides different quadrilaterals with the same mathematical solution. A complex geometry undrawn by conventional methods has been obtained by advancing the cycle one-step further. The algorithm is limited with five iterations. If different iteration numbers and parameters are used, different geometries can be obtained. The design outputs obtained depends on the mathematical expression of the fractal function in the coding lines within the scope of the study.

The second-dimensional outputs provided by the generative fractal algorithm were useful in deciding the angle parameter defined in the fractal function. After this stage, the generative algorithm system iteratively provided generative proposal outputs in the third dimension. In the first step of generating the outputs, the generative fractal algorithm system enabled the coordinates to be defined from the two parallel sides of the column. Consecutively, a line is defined on the edges by connecting two points randomly chosen by the generative algorithm, and by this means, the defined lines together form surfaces. Surfaces take place in various coordinates in each iteration through the function that defines random axial motion in the algorithm. In addition to axial variation, each iteration produces fractal geometry in three dimensions. In the process of generating new geometries of the generative system, for each stage of the algorithm, a new axial variation occurs. With the increase in the number of iterations, the concept design has turned into a complex structure (Figure 6).

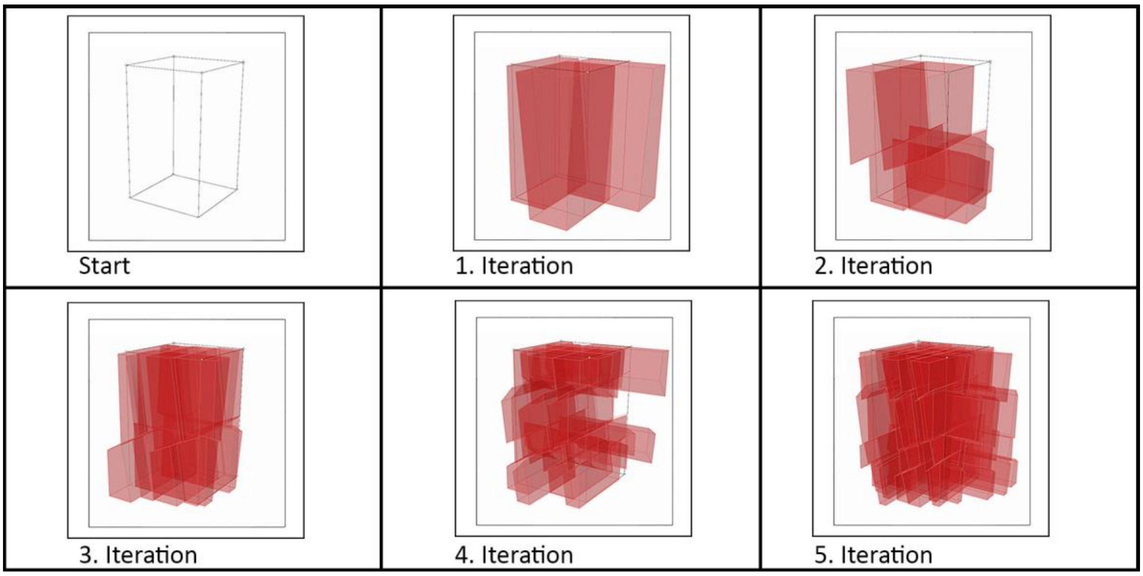


Figure 6. Third dimension outputs of the generative fractal algorithm designed with Python (Prepared by the Authors)

Throughout the process, it has been observed that the axial mobility of the fractal surfaces formed as a result of new productions at each stage by the algorithm allows for generative system design diversification, although the algorithm is produced based on a single fractal function. The production of various proposals of "design by the algorithm" has led to the generation of a large number of fractal geometry, such as a unit in the algorithm during the design process. For this reason, in order to control the geometric organization in the algorithm, the fractal unit number, as a result of each iteration provided to the algorithm, and each point in the space geometry system defined and listed. In this way, complex geometry became definitive and controllable (Figure 7).

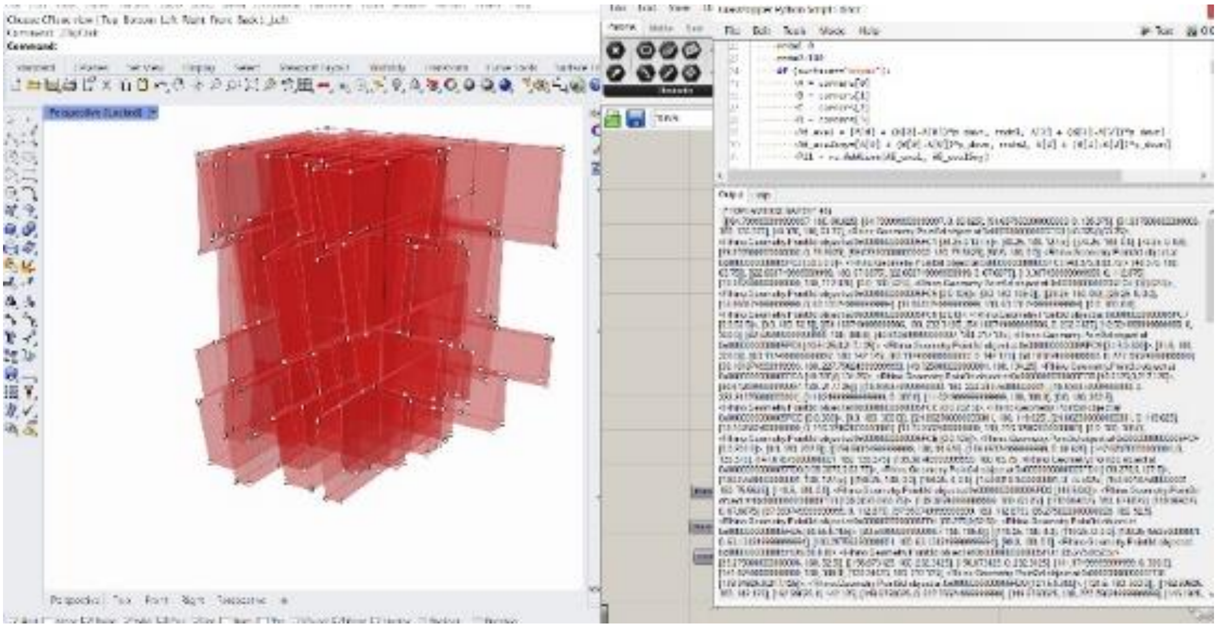
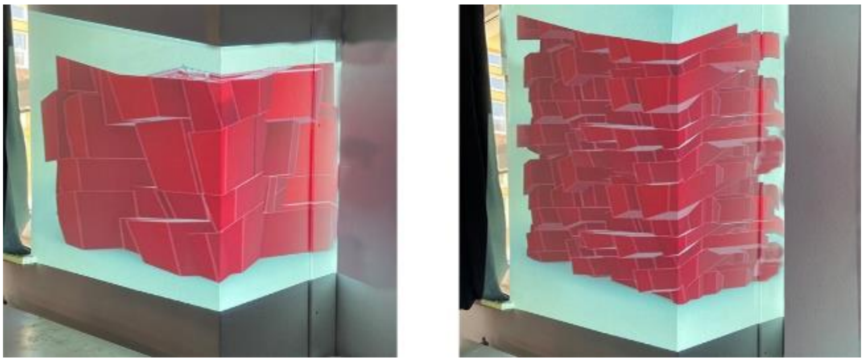


Figure 7. The location coordinates of the geometry produced by the algorithm and the generation of the fractal unit number by the algorithm (Prepared by the authors.)

As a further step in the study, the design outputs of the design geometry produced by the generative fractal algorithm system were integrated with the video projection mapping method to the region defined on the column (Figure 8). In order to do that, video projection mapping was performed by defining the column dimensions as parameters in the algorithm (Figure 8.a). As it is observed, the algorithm gives a new output with the change of the vertical dimension parameter on the geometric output produced by the generative system (Figure 8.b). It is clear that, the size parameters of the column surface and the algorithm determined at the beginning were important factors in the production process. As a conclusion, there are differences in the output production potentials provided by the algorithm with the diversification of the size constraints.



(a) **(b)**

Figure 8. Transfer of design outputs produced by the generative fractal algorithm system with video projection mapping (Prepared by the authors).

4. RESULTS

If the algorithm is defined as a certain number of parameters running in a finite time period of defined work, it can also be solved by iterative generation algorithms which are the basis of fractal geometry. This feature of fractal geometry facilitates prototyping in architectural designs. Thus, the different outputs provided by the generative algorithmic systems at the beginning of the design phases allow various solutions to the architectural design problems in the second and third dimension.

In this study, the generative algorithm is visualized in Rhino, which is encoded in Python in the Grasshopper interface. A variety of potentials in the design process is proposed by obtaining the second and third dimensional outputs of the generative fractal algorithm system. The planning decisions to be made in the design phases are diverse with the algorithm producing outputs in the second dimension. The outputs in the third dimension enabled the production of suggestions for the diversification of the multiple fractal units that come together on the architectural picture plane as forms of image frames. The generative algorithm system provides outputs in the second and third dimensions simultaneously. Planametric and third dimension variations, which are the main elements of architectural design, produced “a coordinated generative algorithm system”. Thus, parametrically controllable and definable fractal geometry outputs were obtained with the generative algorithm system. During the production of geometrical outputs, the function of fractal geometry defined in the Python code was the most effective parameter in both the second and third dimension. Although the axial mobility in the third dimension within the generative algorithm system is produced depending on the fractal algorithm function that is defined at the beginning, it has been observed that the generative system continues to diversify on the geometric outputs. The number of fractal units in the diversified geometric outputs and the position vector of each point in space geometry can be defined; calculated and observed as output. It is envisaged that these calculated outputs can be useful in interdisciplinary studies during the realization process of the design (architectural surface, column, façade, ground floor etc…) and contribute to the working process in future.

The integration of generative algorithm-based architectural designs with the video projection mapping method has enabled the visualization of the change in the actual measurement parameters of the design. It has been observed that the actual dimensions of the design are included as parameters in the algorithm. Furthermore, it was predicted that the various outputs of the generative algorithm may be efficient in the production process. In addition, it ensures that the design achieved in the design incorporates into the actual dimensions without the need for materials and construction processes by defining the actual dimensions as parameters. Therefore, it is expected that the study will contribute to the research and development of diverse potentials in architectural facade or plane designs with generative systems.

In this study, the importance of the designer's development of the original algorithm in digital design was emphasized because the outputs generated by the generative algorithm cannot be directly produced computationally through softwares and modeling programs. As the generative algorithm of geometries is established by the designer, the constraints of the interfaces of modeling programs are removed. In conclusion, the interfaces of modeling programs are no longer a restrictive factor in the design process, so these various potentials of the design are observable in computational design processes. In addition, it has been evaluated syntactic coding languages can take place as “a new solution skill” in the design discipline with the development of designer-specific algorithms.

CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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DEMYSTIFYING MACHINE LEARNING FOR ARCHITECTURE STUDENTS

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ABSTRACT

With the developments in technology, mass data, new approaches/tools, and the increasing inclusion of machine learning applications, the necessity to teach these concepts and their applications have emerged in all research areas including architecture. In this context, a new course named "Machine Learning Applications in Architecture" containing lectures on data, data literacy, patterns, and various kinds of models along with a project conducted by the students was developed and started to be taught in spring'2020. Conducting a class on relatively new subjects for students was a great challenge. Yet, with a well-defined problem-based learning approach, the adaptation of students to the subject took place immediately. It is important to note that as students are equipped with information on machine learning concepts and applications with the given lectures, they were free to choose the project topics of their own which are believed to be one of the reasons for the success of the end results. As a result of this class, the project topics varied widely as coloring a given painting, predicting the era of a building, interpreting 2D drawings for 3D modeling, optimizing daylight gain, analyzing distinctive features of data in a city, and visualizing data to represent various aspects in data. The outcomes of the class are documented and analyzed to show how information in different fields such as computer science, engineering, statistics, and so on can broaden their thinking of how to attack problems in the architectural design domain. Finally, topics such as data, data literacy, pattern recognition, and intelligent models are projected to play a key role in the future of design education since it provides an interdisciplinary ground to think about problems at hand from a distinct perspective.

Keywords: Machine learning, Architecture education, Data literacy, Data-model matching

1. INTRODUCTION

Advances in technology, the abundance of data mass, tools easing the adopting new approaches, and increasing involvement of machine learning applications in architecture increase the interests of students in these areas and application studies. Ever since artificial intelligence and machine learning became a 'buzzword' for every domain, the necessity to teach these concepts and their applications have emerged for all research areas including architecture [1,2]. With the increasing involvement of computational design, data becomes the main input, and data visualizations have already turned into forms with algorithms/models developed or compiled by designers. Today, considering that form finding has started becoming an archaic term, data itself and data visualization are taking its place for design disciplines, especially for architecture.

In education, computational design and then machine learning become key topics with offered courses in various universities such as "Machine Learning for Creative Design" at Massachusetts Institute of Technology [3], "Artificial Intelligence in Architecture" at Institute for Advanced Architecture of Catalonia [4], "A.I., Machine Learning, and the Built Environment" at Harvard Graduate School of Design [5], "Data Science for Construction, Architecture and Engineering" at National University of Singapore [6], and so on. Therefore, it can be easily observed that the field of computational design started to focus more on trending subjects in computation that are machine learning, artificial intelligence, and data science.

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In this context, a new course named “Machine Learning Applications in Architecture” offering lectures on data, data literacy, patterns, and various kinds of models along with a project that is planned to be conducted by the students was developed and started to be taught in spring’2020. Then, in spring’2021 term, the course is offered to graduate students in the department of Architecture. With these experiences, we would like to share not only our teaching experience or outcomes but also the “to do” and “not to do” lists for future classes.

2. DATA LITERACY

At the beginning, conducting a class on relatively new subjects for students was a great challenge. Yet, with a well-defined problem-based learning approach, the adaptation of students on the subject took place immediately. In this period, terms, data literacy, and the concepts of data mining, labeling, and matching are introduced to the students. In this vein, along with the concepts of data science, the importance of domain knowledge is worth mentioning considering the specific knowledge of students of the department of architecture related to visualization, representation, and classification. Hence, it can be said that coming from an architectural background helped students to understand and implement data visualization and having knowledge on computational design aided them to comprehend mathematical concepts behind machine learning models. Based on that, it should be noted that data literacy and domain knowledge have filled a critical gap when it comes to implementing machine learning algorithms to specific problems observed and defined by the students.

Analyzing the projects completed in the scope of the course, the process of each project can be summarized with four main steps that are: formulating the problem, acquiring and processing the data, determining the model, and visualization of results. Yet, it can be observed that each project focused on different steps of the overall process. For example, in one project aiming to predict the corresponding three-dimensional (3D) model of a tree based on a given two-dimensional (2D) drawing, it can be observed that labeling the acquired data and determining the model architecture was the focus. On the other hand, in another project aiming to enhance the visual connection between interior and exterior of a building provided by visibility prediction based on 2D plan layout data, it can be said that formulating the problem and visualization of results was the focus. Therefore, exemplified by these two projects, outputs of each project completed in the scope of this course have shown diversity. For comparison, the data preparation phase of projects; 3D tree model prediction from 2D drawings (Figure 1), and the study analyzing and aiming to enhance the visual connection between interior and exterior (Figure 2) are presented below.

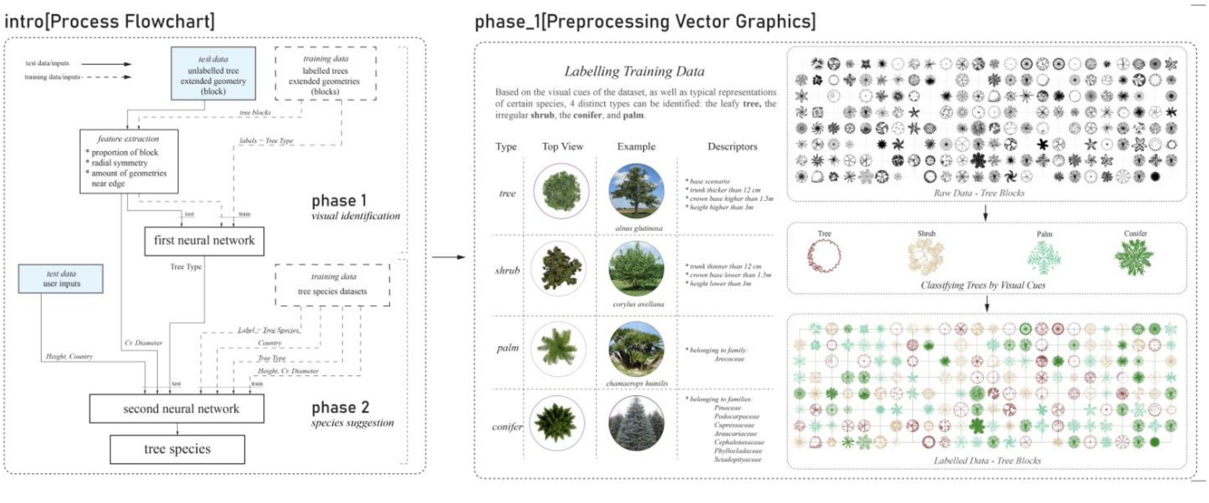

Figure 1. Data preparation for 3D tree model prediction from 2D drawings (developed by Hammad Haroon)

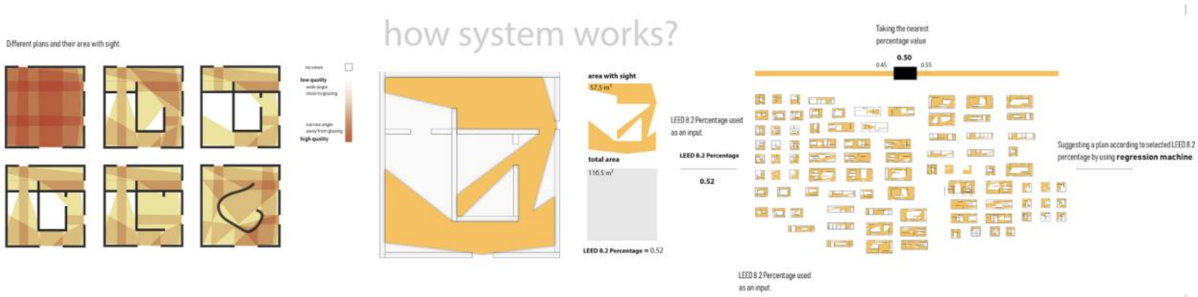

Figure 2. A case on sight of a space (developed by Nilra Ayşegül Zoraloğlu)

3. DATA AND MODEL MATCHING

Following the data preparation processes, it is seen that matching data with the design process in terms of form, function, generation process is found valuable to be explored in architecture with many examples and in-class assignments. In the two semesters that the course is offered, different approaches are embraced. For the first term, students are asked to locate, collect, or create their own datasets depending on their problem definition. Then, for the second term, New York City Database (https://opendata.cityofnewyork.us/data/) is assigned considering the wide variety of data sets included that can serve for a wide variety of problems.

As a result of this difference, students were able to adapt themselves in terms of the tools used for the project, data processing strategies, model selection, and data visualization techniques. For example, when the students are asked to find or generate their own datasets, most of the students tend to use the tools that they already know such as Grasshopper; but when the case is switched in the next term where students were assigned the New York City Database [7], students tend to learn new tools such as Python. Moreover, data processing techniques were switched from feature extraction from geometry to statistical methods in general depending on the difference between terms. Furthermore, model selection is also affected since available methods and community behind tools differ greatly. Yet, the switch from expecting datasets from students to assigning a predefined dataset created a difficulty in terms of producing visual outcomes of the models. Finally, problem definitions, datasets and used models for two terms are presented in the Table 1 below in order to provide a general picture.

Table 1. Matrix of problem definitions, data sets and selected models (developed by the authors based on student projects)

Problem	Term	Data Set	Main Strategy	Model	Main Tool
Visibility Analysis	s'2020	2D Plan Layouts and Wall Locations (Generated)	Geometry Processing	Regression	Grasshopper
Tree Suggestion	s'2020	2D Tree Drawings and Names of Species (Collected)	Geometry Processing	Classification	Grasshopper
Date Prediction	s'2020	Building Photographs and Construction Dates (Collected)	Image Processing	Classification	C# (.NET)
Data Visualization	s'2020	Climate Data and Corresponding Locations (Obtained)	Data Clustering	Regression	Grasshopper
Image Coloring	s'2020	Painting Images of Famous Painters (Collected)	Image Processing	Regression	Python
Direction Control	s'2020	Wind Directions and Intensions (Generated)	Geometry Processing	Regression	Grasshopper
Air Quality Prediction	s'2021	Air Pollution and Particles in the Air (Obtained)	Statistical Analysis	Regression	Python
Vehicle Safety Prediction	s'2021	Vehicle Collisions and Crash Reports (Obtained)	Statistical Analysis	Classification	Python
Mapping of Constructions	s'2021	Construction Jobs and Locations (Obtained)	Data Clustering	Classification	Grasshopper
Energy Score Prediction	s'2021	Energy and Water Usage (Obtained)	Statistical Analysis	Regression	Python
Incident Prediction	s'2021	Incidents and Crime Reports (Obtained)	Statistical Analysis	Regression	Python

4. RESULTS

As students are equipped with information on machine learning concepts and applications with the given lectures, and hands-on workshops, they were free to choose the project topics of their own which are believed to be one of the reasons for the success of the end results. The project topics varied widely as coloring a given painting, predicting the era of a building, interpreting 2D drawings for 3D modeling, optimizing daylight gain, analyzing unique features of data in a city, and visualizing data to represent different aspects in data. The outcomes of the class are documented and analyzed to show how information in such a different field such as computer science, engineering, statistics can broaden their thinking of how to attack problems in the architectural design domain. Finally, topics such as data, data literacy, pattern recognition, and intelligent models are projected to play a key role in the future of design education since it provides an interdisciplinary ground to think about problems at hand from a different perspective.

This result can be observed in project results in different aspects. For example, in one of the examples completed in spring'2020, the problem is defined as predicting the era of a building from its photograph (Figure 3). Since the dataset was limited compared to other well-known image processing examples like classifying objects or animals, data augmentation was implemented by rotating, scaling, and cropping the images and adding them as new samples to enlarge the limited dataset which inevitably increased the accuracy of the model. Hence, it can be said that available approaches in other domains (such as computer engineering) were successfully discovered and implemented to overcome challenges of the architectural domain (such as lack of available data).

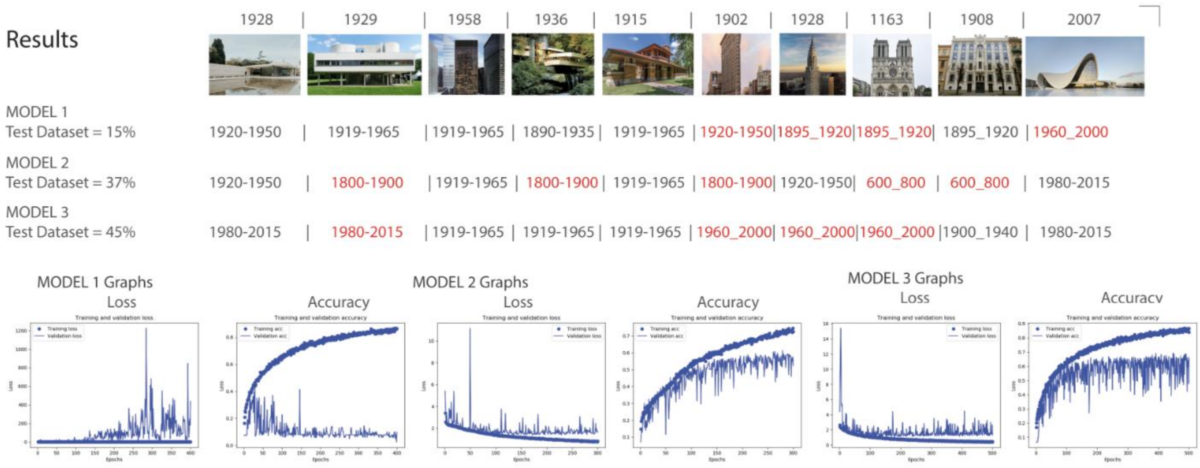

Figure 3. Results of multiclass architectural period classification model (developed by İsmet Berke Çakır)

Similarly, in another example from the same term, image processing was used in a different way to the defined problem of coloring a given black and white image (Figure 4). In this project, the dataset is curated in a way to provide different coloring strategies, unlike available approaches in other domains that also aim to color the given image. Hence, the project was able to color the given image with the color palettes of famous artists such as Vincent van Gogh, Raphael, Frida Kahlo, Edgar Degas, Pablo Picasso, and Amadeo Modigliani. Therefore, it can be said that the project successfully transformed the well-known problem with a touch of domain knowledge and proposed a novel approach.

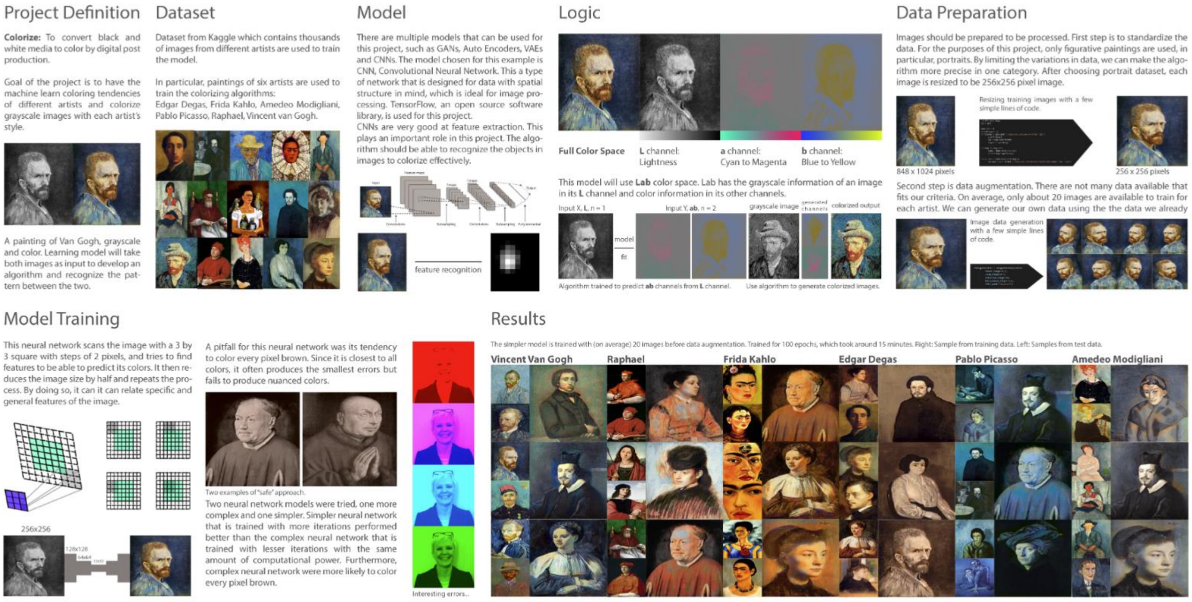

Figure 4. Colorizing with painting (developed by Ege Doğan)

Moreover, when the works developed in spring’2021 are analyzed, it is possible to see that the focus was more on the engineering side since the source of the data is already provided. For example, in the example of predicting energy star score from energy and water usage data, pairwise feature visualizations and a correlation matrix were used to demonstrate and select which features of the given data affect the energy score more. In another example from the same term, data were analyzed by means of a tree structure so that features of data were put in a hierarchical way from general to specific and construction works in NYC are visualized accordingly.

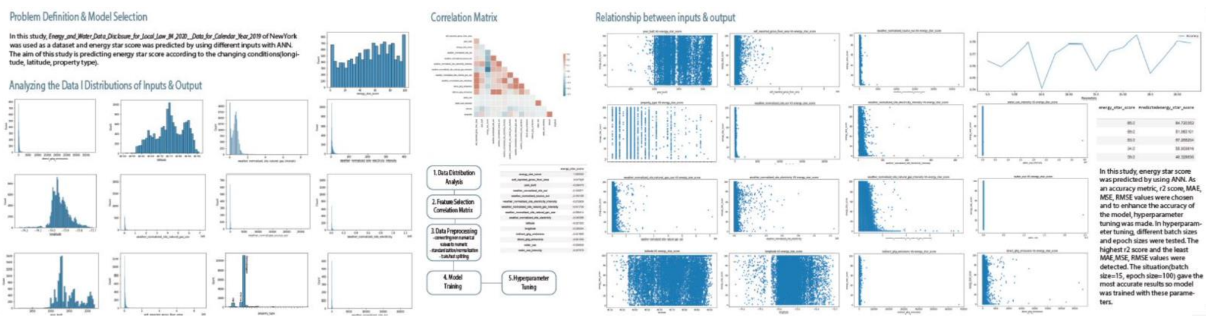

Figure 5. Results of energy star score prediction model (developed by İlkim Canlı)

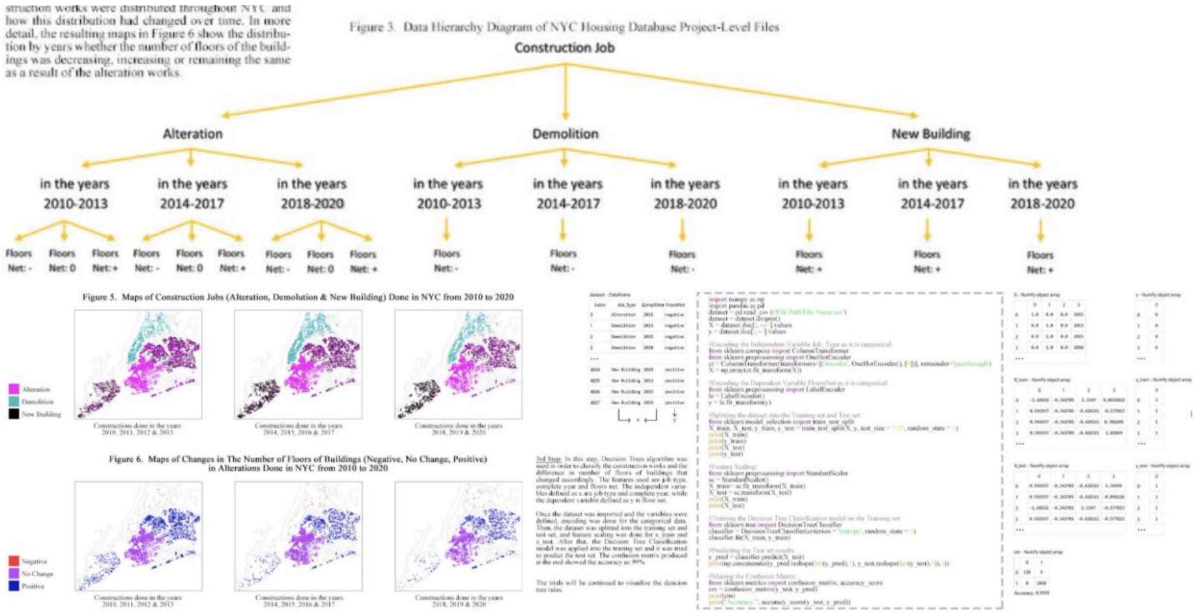

Figure 6. Model for understanding and mapping construction works in NYC (developed by Hatice Hilal Topuz)

5. DISCUSSIONS

In the first semester, students are asked to find or provide their own datasets, then in the second term, New York datasets are provided to be worked on. In each semester, the synthetic nature of the datasets and the role of augmentation are discussed. In both cases, they were free to choose their problem according to their curiosity. It is believed that defining the question and finding their curiosity which is what they want to learn is crucial instead of what they can do with the obtained data and the models. Yet, while constructing their questions, considering these exercises are their first encounter with ML models, students are directed toward quantifiable issues instead of topics like perception, creativity, and so on.

While structuring datasets provides students more control over their data and choosing a model, provided datasets lead them to find cross relations and merging different datasets as well as exploring different models. For both cases, it is seen that, when the obtained/collected/generated data are too complex, it becomes hard for students, who are new to the subject, to find the correlations and thus, understand and assess the models and results. Although there are many sources providing ML models, it is believed that fundamental statistical knowledge including manual calculations of probability, ANN etc. is crucial.

In each semester, students are offered tutorials on Python and Lunchbox add-on of Rhino-Grasshopper [8]. Based on the background and existing skills of students, they either developed their own model, or use Python models provided in databases like GitHub [9]. Although the models that are developed by students were less complicated than others, it is seen that at the end, they had more control and knowledge about how it works, and their results.

6. CONCLUSION

In this paper, the outcomes of the course “Machine Learning in Architecture” class are presented with the conduction of the terms and the lessons learned throughout the two semesters. The first point to mention is the importance of data literacy and adapting to the changing role of data visualization in computational design. Then, the introduction of machine learning’s fundamental topics like probability, statistics, feature extraction, labeling is found vital for the conduction. As the most critical part, the importance of the domain knowledge, which is architectural knowledge in this case, has played a crucial role throughout the term. The specific knowledge of any domain is important for any ML application in that domain considering the fine tasks like data preparation, labeling and model selection.

Above all course objectives, at the end of the semester, students are expected to accept that ML is merely a tool for understanding, modeling, and predicting, and therefore no more mystical than any computational tool. Considering the literacy between data and information is being lost, it is aimed to re-establish this relation again for students. Hence, it is very important for students to understand the following: ML is neither a magical tool that only takes data and handles the rest by itself nor a very complicated one that needs to be analyzed and structured to its every bit.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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EFFECTS OF PHOTOBIOREACTOR FAÇADES ON THERMAL AND VISUAL PERFORMANCE OF AN OFFICE IN IZMIR

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ABSTRACT

Due to the increasing environmental awareness, the tendency to develop sustainable buildings has also increased interest in using renewable energy or energy-efficient technologies in recent years. Integrating a photobioreactor, an innovative building element on the façade, has received attention as an alternative approach to renewable energy systems for its potential to reduce the carbon footprint and energy consumption of a building without compromising thermal and visual comfort. This study aims to improve the performance of the building by using a façade integrated photobioreactor system. Implementing photobioreactors on the building façades raises the following benefits a) regulating the indoor temperature swings and improving thermal comfort, b) blocking the excess daylight thanks to the increasing concentration during the algae growth, c) reducing the energy consumption of the building, and d) producing energy from the harvested biomass (algae). The photobioreactor is integrated into the south façade of an existing office building in Izmir and comprises two glasses and a growth medium of photosynthesizing microalgae between the glasses. The method is simulation-based optimization that maximizes useful daylight illuminance and minimizes thermal comfort violation and energy use intensity. The performance of the existing building was compared with two photobioreactor alternatives. Rhino Grasshopper software with the Octopus plugin was used for the optimization study. The optimization results show that the photobioreactor integrated façade system performed better than the currently used one. The photobioreactor integrated façade can reduce the number of uncomfortable hours during the year. For the investigated photobioreactor configurations, there was no significant difference between 100% photobioreactor façade and 80% photobioreactor façade, except for partial improvement in daylight illumination.

Keywords: Multi-objective optimization, Microalgae photobioreactor, Building performance, Thermal-visual comfort

1. INTRODUCTION

The design decisions made in the early design phase of the buildings significantly affect the daylight, comfort, and energy performances. In addition, taking various precautions against problems that may arise in the future is possible. The building envelope is directly in contact with the outdoor environment and is responsible for an average of 75% heat gains and losses [1]. Especially the window element usually has an overall heat transfer coefficient of typically five times greater than the other components in the building envelope. Hence, these transparent surfaces cause 60% of the total energy consumption of buildings [1]. Thus, it is crucial to choose the window element correctly, but multiple parameters need evaluation to improve the building's performance.

The properties of the building envelope components determine the building's performance. The trends and thoughts of architects in buildings working with algae can help form an idea of the requirements and possibilities needed in the architectural design of such buildings. It can bring different perspectives on different subjects, such as biomass production with algae grown inside, contributing to the thermal energy balance with solar energy gains, and lighting with a change in light transmission depending on time. In this direction, researches show that using microalgae, an innovative alternative to envelope components, will enable buildings to be more sustainable and contribute positively to the energy

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balance. Kim [2] examined the PBR's daylight considering the thermal and structural performances by proposing a microalgae façade panel comprising two zones (algae and vision zone). She concluded that algae façade systems could visibly improve buildings' thermal and daylight performance. Decker et al. [3] showed that microalgae growth and daylight penetration are interdependent, and various culture densities can affect indoor daylight intake. Lo Verso et al. [4] used PBR as a shading element and analyzed the daylight performance in an outdoor working area under PBR shade with DIVA-for-Rhino software. In that study, the illumination values changed for different light transmittance values. The authors changed the light transmittance by adjusting the biomass density in the culture medium circulating inside the panels. Cervera Sardá and Vicente [5] stated that by adding PBRs to buildings, the microalgae absorb the sunlight by photosynthesis, lower the temperature via the shading effect, and increase the energy savings because the microalgae growth medium increases the acoustic and thermal insulation performance of the façade and mainly contributes to temperature reduction. Negev et al. [6] studied the effects of PBRs on the energy consumption of buildings in the Mediterranean climate and showed that including windows in the building façade, mostly in west and south orientations, provides energy savings compared to single and double-glazed windows.

Studies on the effect of one parameter on a PBR façade element are present; however, studies optimizing PBR façades for high daylight performance and low energy usage are quite limited. Köktürk et al. [7] investigated the useful daylight illuminance (UDI) and energy use intensity (EUI) values in a hypothetical office space in the Ankara climate, depending on the window-to-wall ratio (WWR) and algae concentration variables for the north and south directions. There are no other simulation-based studies on this subject in Turkey. In addition, although there are some studies where these innovative systems present PBR façades as an energy-friendly alternative to traditional window systems, there is no attempt to optimize their thermal comfort performance. This study aims to investigate the effects of the thermophysical and optical properties of a PBR façade on energy consumption, daylight illumination, and thermal comfort in an office room in İzmir. This study examines the main design parameters of the PBR integrated façade such as WWR, algae concentration, wall type and thickness, insulation material thickness, and heating-cooling set point. The objectives of the simulation-based optimization are to reduce EUI and thermal comfort violation (TCV) and to increase the UDI.

2. MATERIALS AND METHODS

The current research uses different tools holistically to evaluate the dynamic thermal and visual behaviors of existing office space in İzmir. Building geometry comprises multiple areas created by Rhinoceros software, then converted to thermal zones in Grasshopper. The validation of the energy simulation was performed according to the criteria defined by ASHRAE [8] by comparing the indoor temperature results from the simulation with measured temperatures to prove the validity.

After validating the simulation, a single zone for a PBR was created in two different ways. In the former, as in Negev et al.'s [6] study in the literature, the PBR is 100% filled with a growth medium. In the latter, the PBR has a 20% air gap and 80% microalgae growth medium following realistic working principles (Figure 1).

Daylight simulation is the next stage. The lighting schedule obtained from the daylight simulation model is integrated with the energy simulation. EnergyPlus/Openstudio engine evaluated the energy performance, while Radiance/Daysim engine simulated the daylight performance. UDI, TCV, and EUI metrics were calculated during the simulations. Optimization was carried out on Rhino Grasshopper software using the Octopus plugin. Optimization objectives are related to daylight, energy, and thermal comfort and enable the analysis of the relationship between building design variables and performance metrics. In optimization, the design variables and ranges are set as follows. The window types are PBRs that are prepared to depend on the algae concentration with an increase of one day. Window to wall ratio has been adjusted from 10% to 95% in increments of 5%. Wall types are brick and aerated concrete. Both wall thickness and insulation material thickness differ. While cooling set points varied from 23.5°C to 27° with 0.5°C increments, heating set points varied from 18°C to 23.5°C.

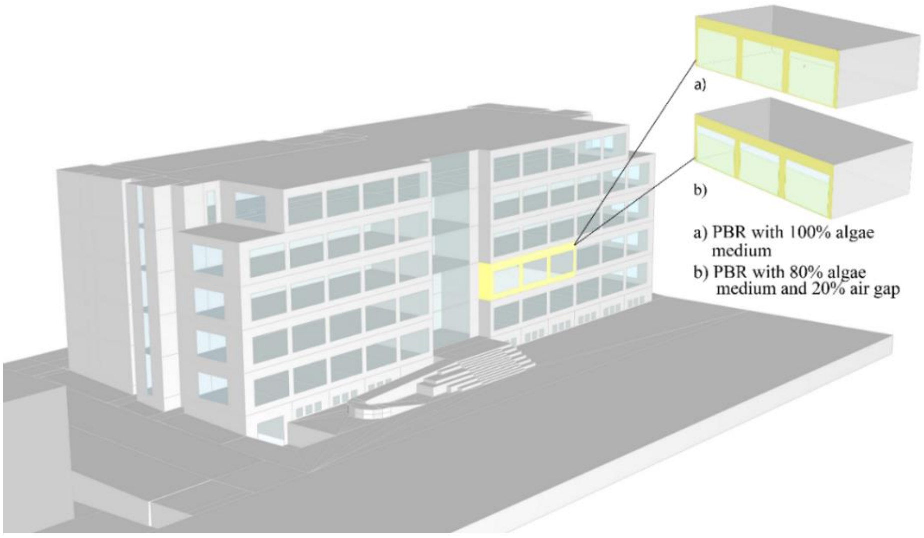

Figure 1. Façade alternatives

3. RESULTS AND DISCUSSIONS

The building model has two different PBR façade element modeling proposals (as seen in Fig. 1). The solutions obtained by optimizing the existing building and the alternatives to improve this façade are compared and evaluated in terms of the thermal and visual comfort performance parameters.

3.1. Photobioreactor Façade Fully Filled with Growth Medium

The independent variables in the analyzes were PBR-related design variables (WWR and window type), temperature control settings (heating - cooling set points), the wall type-thickness, and the thickness of the insulation material used in the wall. By calculating the fitness function in the solutions obtained at the end of the optimization, balanced solutions were obtained between daylight, energy, and thermal comfort performances. Optimization results are given in Table 1. Table 1 shows that the UDI changes in the range of 51.81% to 65.12%. It should be noted that UDI is only affected by window type and WWR. At the same time, the WWR should be adjusted depending on the algae concentration. It has been observed that as the algae concentration increases, the amount of light entering decreases, so the WWR increases to provide the UDI. The optimal results have a WWR varying between 15% to 25% in the PBR with algae concentration on the first day, and this ratio varied between 20-30% in PBR with algae concentration on the 2nd day. As the algae concentration increases inside the PBR, the light entering the indoor space decreases because of the increasing shading effect. As a result, the UDI reduces; that is, PBRs with high light transmittance were more common in optimization.

The relationship between the UDI value and the energy used for lighting shows that as the UDI decreases, there is a reduction in the use of daylight in the space. According to this reduction, the energy consumption for artificial lighting increases. This result has been provided by the integration of lighting control systems as well as WWR and algae concentration parameters.

EUI is affected by all parameters, and EUI values change between 544.05 and 1094.86 kWh/m^{2}y. In all optimum solutions, the wall type is only autoclaved aerated concrete (AAC). The wall thickness varied. In the same way, the thickness of the insulation material is also found in different thicknesses. Wall type-thickness and insulation thickness are less effective on the EUI than the other parameters. The cooling setpoint was constant at 23.5°C for each optimal case. Except for one case, the heating set point was identical to the cooling set point. Increasing the heating setpoint from 23°C to 23.5°C in the same configuration improved the TCV, but it increased the energy consumption for heating.

It is necessary to be careful in window designs, as the heat brought into the room by the solar radiation from the windows can cause overheating during summer, decrease indoor thermal comfort, and increase cooling energy consumption. This means that more air conditioning systems consume more energy to bring indoor temperatures to comfortable levels. As the window sizes increase, the cooling loads also increase, and in the Izmir climate, where cooling is dominant, window sizes are generally small. Similar results were found in terms of WWR in studies conducted in the Mediterranean climate in the literature. Acar et al. [9] found the optimal WWR of the Mediterranean climate building as 18.6% and 30.2% for buildings in the cold climate in the optimization they made for the Mediterranean climate and cold climate separately. Goia [10] optimized the WWR in the building envelope in different European cities and reported that the WWR of south-facing windows in Rome and Athens was 20%. However, a lower limit should be set on window widths in climates where cooling is dominant. Because although small dimensions improve thermal performance, they may not provide sufficient lighting.

The window's solar heat gain coefficient value is important to examine the effect of the window type on the energy performance. When the algae concentration increases, the energy used for heating increases in the same configuration, and the energy used for cooling decreases. Heat gain is an essential parameter in the cooling load calculations. PBR types with solar heat gain coefficients of 0.5 and 0.67 were optimal in the Mediterranean climate. This situation is similar to the optimization results made by Badeche and Bouchahm [11] in a city in Algeria with a Mediterranean climate. In that study, the solar heat gain coefficient of the window was found to be optimum between 0.5 and 0.7.

In the results, TCV values are below 10%, which is the ASHRAE recommended value. According to the table, WWR and heating set points must be proper to improve thermal comfort. Unless those parameters are adjusted correctly, more energy will be used to provide comfortable indoor conditions. The increase in algae concentration in the same configurations also increases thermal comfort.

Table 1. Alternative 1- Pareto optimal solutions

Window-to-wall ratio (%)	Window Types	Wall Types/ Thickness (cm)	Insulation Thickness (cm)	Cooling Set Point (°C)	Heating Set Point (°C)	UDI (%)	EUI (kWh/ m^{2}y)	TCV (%)	Cooling (kWh/ m^{2}y)	Heating (kWh/ m^{2}y)	Lighting (kWh/ m^{2}y)	Fitness Function
20	1st day	AAC 25	12	23.5	23.5	60.57	740.46	5.74	667.99	65.57	6.90	64.27
20	1st day	AAC 25	7	23.5	23.5	60.57	740.99	6.06	668.40	65.69	6.90	63.92
25	1st day	AAC 25	12	23.5	23.5	65.12	912.99	8.81	828.08	78.60	6.17	61.50
25	1st day	AAC 25	12	23.5	23	65.12	868.94	10.67	784.12	78.71	6.17	61.11
25	1st day	AAC 25	7	23.5	23.5	65.12	913.43	9.39	828.50	78.77	6.17	60.89
20	1st day	AAC 25	8	23.5	23.5	60.57	671.44	12.63	598.82	65.72	6.90	59.70
15	1st day	AAC 25	12	23.5	23.5	51.81	569.41	3.91	507.95	52.88	8.58	59.39
25	2nd day	AAC 25	7	23.5	23.5	60.51	919.87	5.27	836.00	77.09	6.77	58.04
25	2nd day	AAC 25	8	23.5	23.5	60.51	920.44	5.74	836.44	77.23	6.77	57.52
20	2nd day	AAC 25	12	23.5	23.5	54.62	745.55	4.04	673.57	64.27	7.72	56.94
30	2nd day	AAC 25	10	23.5	23.5	64.08	1094.54	6.89	998.39	89.96	6.19	55.22

3.2. Photobioreactor Façade Air Defined Above The Growth Medium

An examination of the optimal solutions is in Table 2. Window type and WWR were similar as in Alternative 1. WWR varies between 15% and 30% in both PBR with algae concentration on day one and PBR with day two algae concentration. When examining the solution with the highest UDI value (70.16%) among the optimum solutions, it has the biggest WWR and PBR with the highest algae concentration. However, since the energy consumption of this solution is too high, it was well below the desired value in the fitness function calculation. Although the daylight and thermal performance of the building meet the desired values, the energy consumption is not at the desired level. These cases show that as the WWR increases, energy consumption increases to provide thermal comfort in the interior. When looking at the solution with the lowest EUI (399.17 kWh/m^{2}y) and TCV (2.69%) among the optimal solutions, it could not provide the desired value in UDI due to its low WWR. As a result, small window sizes minimize energy consumption, while larger window sizes maximize visual comfort. As can be seen, the sizing of the window reveals contradictions between the two performances. Hence, determining the design according to the fitness function makes it possible to make better choices.

The ideal heating-cooling set point values were both 23.5°C. When the wall type is examined, while the aerated concrete option is common in the first alternative, the brick with a higher thermal capacity has emerged in the second alternative. When considering the wall thickness, options with less thickness are seen compared to the first alternative. While insulation thicknesses vary between 3 cm and 10 cm, the most common choice is 3 cm of the rockwool.

Table 2. Alternative 2- Pareto optimal solutions

Window-to-Wall ratio (%)	Window Types	Wall Types/ Thickness (cm)	Insulation Thickness (cm)	Cooling Set Point (°C)	Heating Set Point (°C)	UDI (%)	EUI (kWh/ m^{2}y)	TCV (%)	Cooling (kWh/ m^{2}y)	Heating (kWh/ m^{2}y)	Lighting (kWh/ m^{2}y)	Fitness Function
20	1st day	AAC 10	4	23.5	23.5	62.18	739.85	6.38	666.98	65.65	7.23	67.07
20	1st day	Brick 17.5	3	23.5	23.5	62.18	741.43	7.44	668.07	66.13	7.23	65.93
25	1st day	AAC 17.5	3	23.5	23.5	65.72	911.87	10	827.23	78.71	5.94	64.76
25	2nd day	Brick 25	8	23.5	23.5	62.96	916.90	6.25	832.32	77.55	7.03	63.98
20	2nd day	Brick 17.5	3	23.5	23.5	58.72	744.63	4.78	672.13	64.76	7.74	62.92
25	2nd day	Brick 25	3	23.5	23.5	62.96	920.14	7.79	934.94	78.16	7.04	62.31
15	1st day	Brick 17.5	8	23.5	23.5	54.96	569.18	4.33	507.77	52.90	8.56	61.69
30	2nd day	Brick 25	5	23.5	23.5	65.37	1092.26	9.17	995.72	90.65	5.89	60.45
30	1st day	Brick 17.5	5	23	23.5	65.99	1032.55	15.26	934.92	92.18	5.45	56.70
15	2nd day	Brick 15	8	23.5	23.5	50.97	571.82	3.62	510.78	52.01	9.04	55.79
10	1st day	Brick 15	7	23.5	23.5	44.43	399.17	2.69	347.93	40.52	10.72	50.41
95	9th day	AAC 10	5	23.5	23.5	70.16	4038.38	11.15	3763.50	269.3	5.53	-8.78

3.3. Comparison of Photobioreactor Façade and Existing Building

Comparisons of two alternative PBR façades and the existing building are in Tables 3 and 4. Examining optimal solutions indicates similarities between alternative façade proposals regarding WWR and window type. For PBR with day one algae concentration, the WWR ranges between 15-30% for both façade proposals. On the other hand, there are different optimal values for PBR with algae concentration on the second day. Among the options balanced with the fitness function, the UDI decreased in the best choice of Alternative 1 compared to the current situation, while the UDI improved in Alternative 2. In other words, the position where the WWR is 20% is not a good option in terms of UDI in Alternative 1 compared to the current situation. In comparison, splitting the PBR in Alternative 2 with the definition of air above the growth medium allows more light to pass indoors, therefore showing better results than in Alternative 1 in terms of UDI.

EUI optimization shows very similar results in the cases of Alternative 1 and Alternative 2 with the same configuration. When the energy usage density of the existing building is examined, the total EUI value per m^2 was found to be 1751.22 kWh/m^2y. Both façade proposals provided improvements ranging from 37.48% to 67.48% and 37.63% to 67.50%, respectively, compared to the current situation.

TCV values are below 10% in all proposals. While the number of uncomfortable hours during the year is 14.70% in the current situation, the number of uncomfortable hours decreases by 2.07-10.79% in Alternative 1, which is full of growth medium. The improvement varies between 0.44-11.21% in the façade proposal, which is 80% full.

Table 3. Comparison of Alternative 1 and existing building

Window-to-wall ratio %)	Window types	UDI (%)	Improvement (%)	EUI (kWh/m^2y)	Improvement (%)	TCV (%)	Improvement (%)
20	1st day	60.57	1.14	740.46	57.72	5.74	8.96
20	1st day	60.57	1.14	740.99	57.69	6.06	8.64
25	1st day	65.12	3.41	912.99	47.87	8.81	5.89
25	1st day	65.12	3.41	868.94	50.38	10.67	4.03
25	1st day	65.12	3.48	913.43	47.84	9.39	5.31
20	1st day	60.57	1.14	671.44	61.66	12.63	2.07
15	1st day	51.81	9.90	569.41	67.48	3.91	10.79
25	2nd day	60.51	1.20	919.87	47.47	5.27	9.43
25	2nd day	60.51	1.20	920.44	47.44	5.74	8.96
20	2nd day	54.62	7.09	745.55	57.43	4.04	10.66
30	2nd day	64.08	2.37	1094.54	37.50	6.89	7.81
30	1st day	66.26	4.55	1086.82	37.94	12.15	2.55

Table 4. Comparison of Alternative 2 and existing building

Window-to-wall ratio (%)	Window types	UDI (%)	Improvement (%)	EUI (kWh/m²y)	Improvement (%)	TCV (%)	Improvement (%)
20	1st day	62.18	0.47	739.85	57.75	6.38	8.32
20	1st day	62.18	0.47	741.43	57.66	7.44	7.27
25	1st day	65.72	4.01	911.87	47.93	10	4.74
25	2nd day	62.96	1.25	916.90	47.64	6.25	8.5
20	2nd day	58.72	2.99	744.63	57.48	4.78	9.98
25	2nd day	62.96	1.25	873.21	50.14	8.88	5.89
25	2nd day	62.96	1.25	920.14	47.46	7.79	6.99
15	1st day	54.96	6.75	569.18	67.50	4.33	10.46
30	2nd day	65.37	3.66	1092.26	37.63	9.17	5.63
30	1st day	65.99	4.28	1032.55	41.04	15.26	0.44
15	2nd day	50.97	10.74	571.82	67.35	3.62	11.21

4. CONCLUSIONS

Simulation-based optimization studies, which provide fast and accurate design guidance to architects, are frequently used to improve the benefits of buildings and seek a balance between conflicting building performance goals. Hence, this study investigated the effect of a nature-based PBR element on the building façade regarding the energy consumption and thermal-visual comfort of an office building. This study analyzed two different PBR façade models for the south façade of an existing office building in İzmir. Optimization results of the proposed PBR integrated façade systems generally showed a better performance than the current design. The shading effect of the algae medium in the PBR filtered out excess daylight; thus, it minimized the visual comfort problems that may occur because of sunlight. Hence, the amount of energy required for lighting reduces. The PBR façades also regulated the temperature distribution in the interior, consequently improving the thermal comfort conditions. In summary, integrating an innovative system such as PBR into the building envelope positively impacts building performance, and it will be an important step towards achieving the goals for a more sustainable built environment. Evaluating the contribution of the effects of the PBR system in the future is possible by examining the cost, life cycle analysis, and environmental performance, besides looking at thermal and visual performances.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

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FROM STITCHES TO DIGITS AND BACK: COMPUTATIONAL CROCHETING OF BRANCHING GEOMETRIES

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ABSTRACT

Crocheting is a hands-on craft that involves repetitive manipulation of a single continuous thread with a hook-like tool to generate surfaces and 3D forms. In a previous study, we have presented a parametric model [1] that generates crochet patterns of NURBS surfaces using a 10-stitches-by-10-rows swatch to account for all the physical variables that affect the crocheted object (i.e., yarn thickness, hook size, crafter's grip). The dimensions of the previously crocheted tension swatches were used as the inputs of the crochet pattern generator algorithm, alongside the desired NURBS geometry, to generate individualized crochet patterns. These crochet patterns are text-based representations, similar to g-code in additive manufacturing, enabling the documentation and communication of the step-by-step hands-on crocheting process. Following these crochet patterns, the users can crochet physical objects with the same dimensions and form as their digitally modeled counterparts.

This paper presents the second stage of this research in which we expanded this computational framework to enable crocheting of parametric branching geometries with multiple components by multiple crafters. While the components of the branching geometries can be crocheted by a single user, it is also possible to have different users crochet the components since the tension swatch can capture crafter-specific variables. As a proof-of-concept, a branching structure made of 14 unique components is designed and crocheted by two students of architecture as part of the Advanced Digital Fabrication course at the Pennsylvania State University. The students each crocheted 7 components based on their individual inputs while maintaining the dimensions and form of the digitally designed branching geometry. The findings suggest the possibility of a collective and distributed crocheting platform which can be used to create crocheted artifacts in various scales. This can be considered an alternative way to transition from the digital to the physical without relying on digital fabrication tools.

Keywords: Digital craft, Computational making, Crocheting, Soft fabrication, Digital fabrication

1. INTRODUCTION

Crocheting is a hands-on-craft technique to produce 3D surfaces by stitching a single continuous thread with a hook-like tool based on instructional patterns. The procedural nature of the craft is similar to g-code in digital fabrication, especially additive manufacturing, due to the defined steps at each manipulation. [2-5] The text-based representation of the crochet patterns also allows documentation and communication of the step-by-step hands-on crocheting process.

In a previous study, we have explored the development of a computer algorithm that generates crochet patterns of single 3D objects modeled in CAD software [1]. In this computational framework, the users first crochet a 10-stitches-by-10-rows swatch. The dimensions (width and length) of the swatch are used as the main inputs of the algorithm, combining all the physical variables that have an effect on the crocheted object (i.e. yarn thickness, hook size, crafter's grip). Based on these dimensions, the algorithm subdivides the 3D modelled objects into nodes, and outputs a crochet pattern in the conventional text-based form. In other words, the algorithm generates unique crochet patterns based on each individual's

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crocheted swatch. Following these crochet patterns, the users are able to crochet physical objects with the same dimensions and form as their digitally modelled counterparts.

This paper presents the second stage of this research in which we expanded this computational framework to enable crocheting of parametric branching geometries with multiple components. As a proof-of-concept, a branching structure made of 14 unique components is designed and crocheted. The findings suggest the possibility of a collective and distributed crocheting platform that can be used to create crocheted artifacts in various scales. This can also be considered an alternative way to transition from the digital to the physical, one that allows precise, circular, and sustainable materialization of digitally modeled objects.

2. CROCHETING: A SOFT FABRICATION METHOD

Crocheting is a textile craft that originated in the 19th century and is similar to knitting. While crocheting as a soft fabrication method in design has not been extensively explored beyond traditional crafts, there are research on delineating the algorithmic nature of crocheting and the potentials of this technique for making architectural artifacts [3–6]. Architectural potentials of knitting, specifically industrial knitting, on the other hand, have been widely explored through various large-scale projects [7–12]. Researchers have also recently explored the use of knitted textiles as formworks for concrete structures in various scales [13–15]. These studies can be considered a testimony for the architectural potentials of crocheting and the need to further explore the causal relations between form and pattern generation to design the crocheted forms in a more controlled way.

The fundamental difference between crocheting and knitting is in the way the stitches are constructed. While knitting stitches are “interlocking loops,” which can make the knitted surfaces multidirectional and flexible, crochet stitches are “knots,” which make the crocheted objects more solid and sturdy. Also, crocheting is done one stitch at a time as opposed to knitting, where all the stitches stay active on the needles until the rows are completed, making the knitted surfaces more susceptible to unravelling. With both techniques, it is possible to make planar surfaces and alter their shapes by increasing and decreasing the number of stitches. While with standard knitting, 3D geometries can be made by joining various planar knitted panels together or by introducing more needles in the process; by working in the round in crocheting, it is possible to make 3D geometries without the need for additional hooks or a panel construction [16]. As a matter of fact, in addition to Euclidean geometries, non-Euclidean geometries can be made with crocheting. Several mathematicians have used the crocheting technique to physically represent complex mathematical models and theories [17, 18].

Existing studies that explore computer-aided crochet pattern generation for 3D objects, such as the Crochet Lathe [19], and Knittink’s Amigurumi Pattern Generator [20], enable the users to manipulate 2D profile curves to generate crochet patterns for revolved surfaces. In both crochet pattern generators the outcomes are limited with axially symmetric 3D objects. In a previous study, we have presented the computational framework to generate custom crochet patterns for various non-symmetric 3D objects [1]. This paper builds on this previous study and expands this framework to generate crochet patterns for branching structures with multiple components.

In addition to the formal complexity that can be achieved through crocheting, as a soft fabrication method, crocheting can enable more circular and sustainable fabrication scenarios. Yarns used in crocheted artifacts can be unraveled and reused multiple times to generate various artifacts. The potential to use crocheted textiles as lightweight structures or flexible formworks in architecture can as well open up sustainable construction possibilities.

3. CROCHET PATTERNS FOR PARAMETRIC BRANCHING GEOMETRIES

Branching structures are based on geometric systems that "expand through bifurcation without returning to form closed cells," and can be used as tension or compression systems in architecture. Various methods have been developed to generate branching geometries since the initial studies by Frei Otto from the early 1960's [21]. In the computational framework that we propose in this paper, branching geometries are generated in three stages. The digital workflow starts with the generation of point clouds in the 3D space (Figure 1a). These points are connected with single line segments to create branching line networks (Figure 1b), which are then transformed into continuous tubular surfaces (Figure 1c). These tubular surfaces are subdivided into branches (Figure 1d) and custom crochet patterns are generated for each branch based on the user inputs (Figure 1e-f).

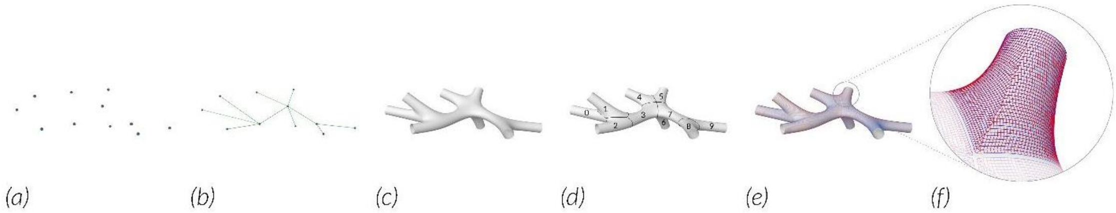

Figure 1. Process to generate branching geometries and crochet patterns simplified and illustrated in steps.

3.1. From Point Clouds to Line Networks

In the computational workflow, we defined three strategies to generate point clouds in the 3D space: a) random points within bounding solids, b) 3D grid-based ordered points, and c) points created on a surface by surface division (Figure 2). Each cluster of point clouds can be varied with parametric inputs that control the dimensions of the geometries and the number of points generated. Random point clouds have the potential to generate more irregular branching geometries. Whereas with grid-based ordered points, it is possible to obtain complexity through repetition. Points generated on surfaces, on the other hand, enable the creation of branching geometries that are constrained on surfaces.

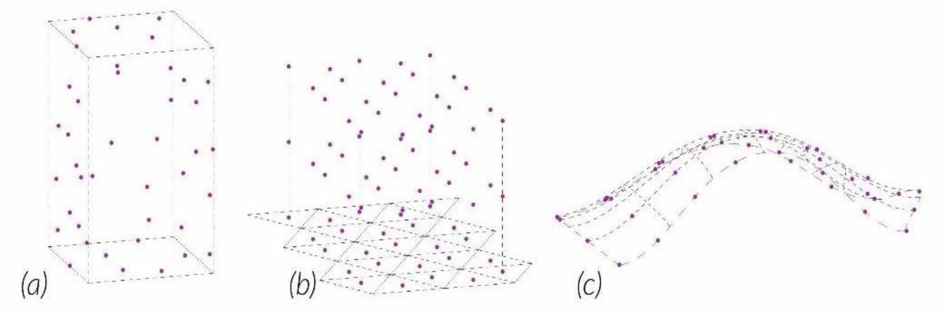

Figure 2. Point cloud generation approaches explored: a) random points in/on a bounding solid, b) 3D grid, and c) points on surface.

The second stage in the process is to connect the points with single-line segments. While this can be done manually, we employed two algorithmic strategies to facilitate the exploration of variations. The first method uses the distances between each node, the maximum number of nodes that can be connected, and the number of iterations for the spread of branches (Figure 3b).

The algorithm uses the closest points to the volumetric centroid as the seed point to spread out at each iteration of branching. It searches the point cloud to find the number of closest points to each point, then checks the number of possible points within a parameterized proximity. To further increase the control over branching and spread, a starting point for the algorithm is introduced. This is done to help the users see the volumetric centroid of the point cloud and select the closest point to this point within the point cloud for an initial branch. By defining the initial point, the users are able to see the branching at each step.

The second algorithm is developed and shared by Petras Vestartas at McNeel forums [22]. The algorithm connects point pairs in the point cloud regarding their proximity and generates points at the middle of each point pair (Figure 3a). The generated middle points are connected with line segments until there are no remaining points to connect. The connected point pairs then get relaxed by the physics engine of the Kangaroo, an add-on of Grasshopper. The relaxed branching structure generates line connection points where the angles between the lines are almost equal and close to 120 degrees. This relaxed geometry allows the construction of surfaces with more uniform curvatures in the subsequent stages, compared with the non-relaxed state and the former algorithm. Figure 3 illustrates how these two algorithms work to generate line networks using the three point cloud examples from Figure 2 as inputs.

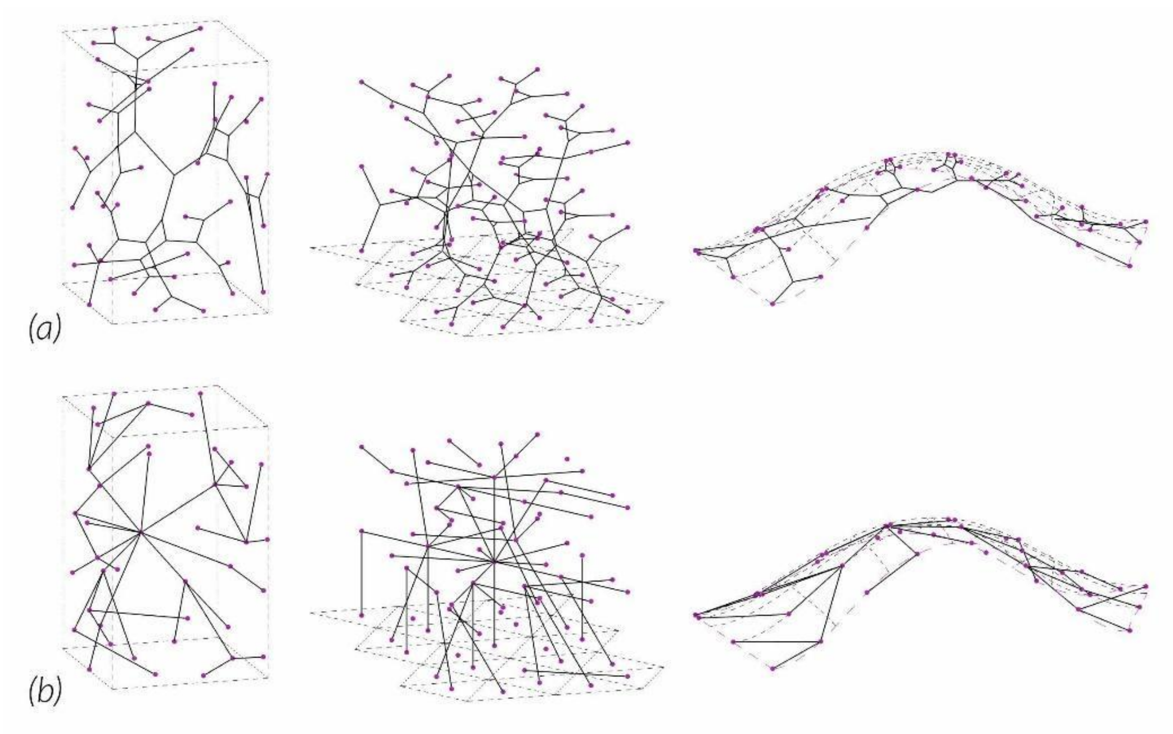

Figure 3. Line networks generated using two different algorithms using the point clouds in Figure 2.

3.2. From Line Networks to "Multipipes"

In the last stage, the "MultiPipe" component implemented within Rhinoceros 7 with the recent updates is used to create "SubD pipe frames with smooth conjunctions from intersected curves" [23]. With the Multipipe component, it is possible to vary the thicknesses of the branches and nodes, and generate smooth connections between the branches. Figure 4 exemplifies some Multipipes created using the line networks from Figure 3.

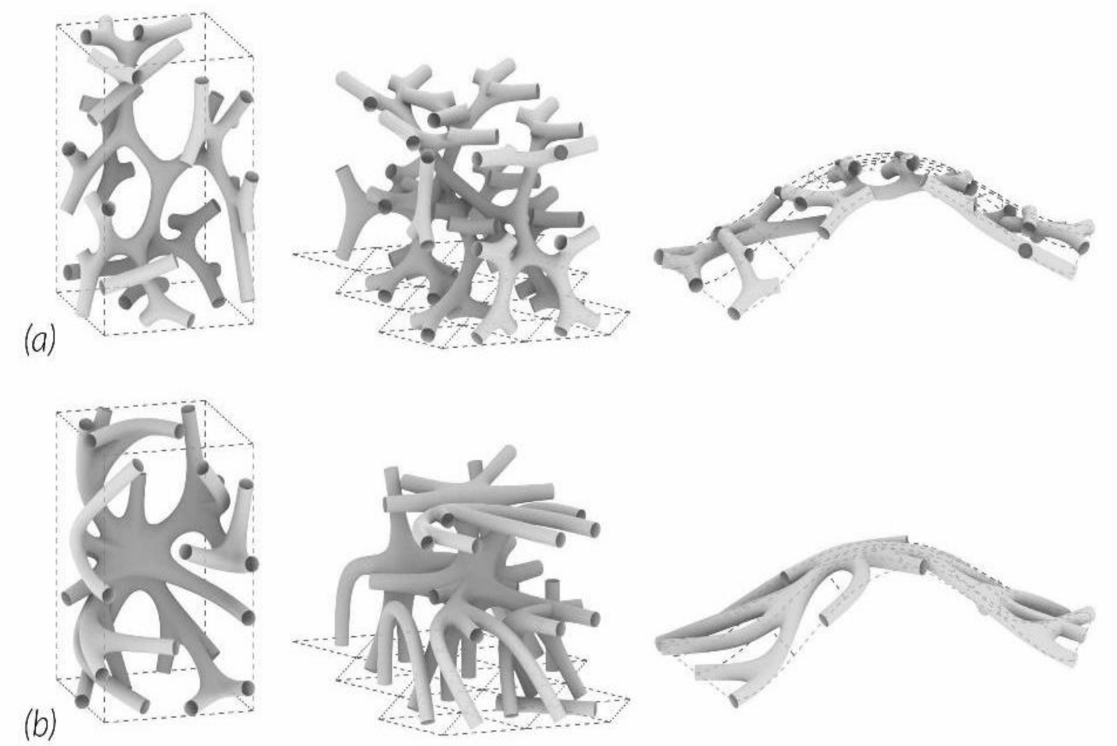

Figure 4. MultiPipe surfaces generated based on the line networks in Figure 3.

The crochet pattern generation algorithm that we have previously developed was based on the NURBS geometry class. SubD is a new geometry class in Rhinoceros 7 that "combines free-form accuracy while allowing quick editing" [24]. Since Multipipe is a SubD component, we needed to develop a method to convert SubD geometries to NURBS geometries. This conversion resulted in branches with multiple SubD surfaces that needed to be restructured as a single NURBS polysurface (Figure 5a) because the crochet pattern generation algorithm works best with single NURBS surfaces. This reconstruction is done in multiple steps. First, cylinders are generated around the branching curves to test whether the centroids of the SubD surfaces are within the cylinders or not (Figure 5b). This allowed the data structure of the branching structure to be mapped on each branching curve. SubD surfaces that are within the cylinders are grouped together. To reconstruct these as NURBS surfaces, planes are arrayed rotationally around branching curves and intersected with the grouped surfaces (Figure 5c). The emerging intersections are combined with the edge curves to create precise NURBS surfaces using the network surface command (Figure 5d). The reconstruction method also serves to check the crochetability of the geometries.

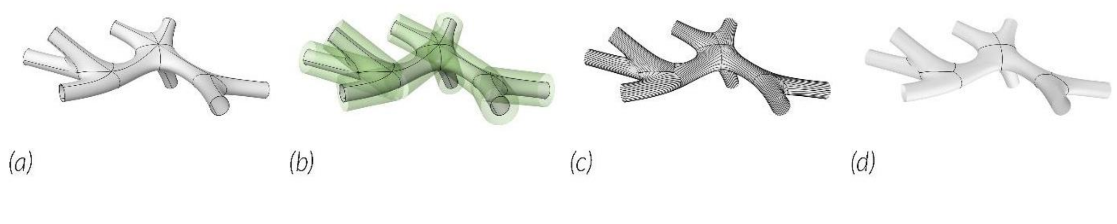

Figure 5. SubD to NURBS surface reconstruction: a) discrete SubD surfaces, b) cylinders around branching curves, c) intersection curves, (d) reconstructed NURBS surfaces.

3.3. From "Multipipes" To Crochet Patterns

Following successful reconstruction of individual branches within the larger structure, these NURBS surfaces are further processed to generate crochet patterns. As previously mentioned, the algorithm to generate crochet patterns from NURBS surfaces is based on the approach presented in our previous work. Together with the 10-stitches-by-10-rows swatch inputs by the users to approximate stitch width and height, this algorithm estimates a graph network of individual stitches which can later be used to export a series of crocheting instructions for each row, customized for the crafter. To achieve this graph network, the algorithm performs a series of geometric decomposition steps on the input NURBS surface. These steps are (b) generation of a spiral conformed to the NURBS surface, (c) division of the spiral into rows, (d) division of the rows into crochet nodes, and lastly (e) generation of the graph network between crochet nodes, as shown in Figure 6.

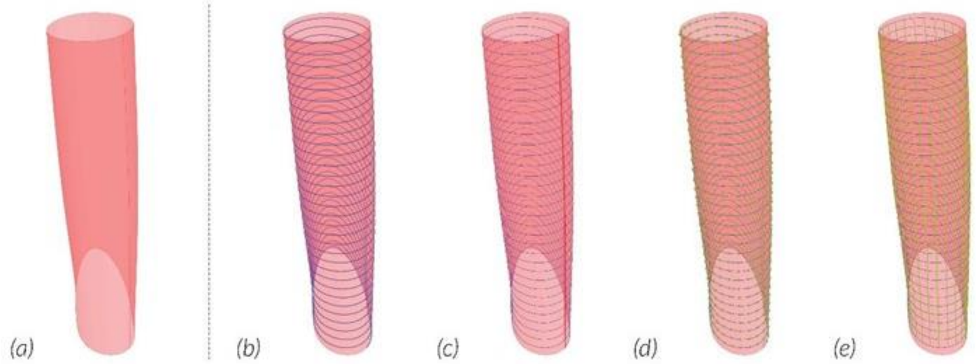

Figure 6. Computational stages of the pattern generation algorithm: (a) input surface, (b) generating the conformal spiral, (c) splitting the spiral into rows, (d) calculating crochet nodes, and (e) generating the graph network.

In the first step, a conformal spiral is drawn on the NURBS surface using UV isocurve intersections sampled based on the calculated stitch height. Following this step, the generated spiral is first split into rows using UV(0,0) isocurve and then divided into crochet nodes that are spaced out per the calculated stitch width. Once the nodes are generated, every node in a layer is compared to the nodes of the subsequent row. This is achieved by first establishing the node pairs between row_n and row_{n+1} by searching for closest nodes in row_{n+1} for each node in row_n. In cases where this proximity pairing results in unmatched nodes, meaning that the surface geometry is bulging out locally or globally between layers in the direction of crocheting, another proximity pairing is carried out. In contrast to the first pairing, however, the order of rows is reversed, searching for closest nodes in row_n for all unmatched nodes in row_{n+1}.

Using this approach, the graph network of node connectivity between layers results in one of the three different stitches: single stitch (st), increase stitch (inc), decrease stitch (dec). By drawing lines based on the connectivity between nodes in row_n and row_{n+1}, this graph network is visualized for the user. Furthermore, by counting the number of nodes in row_{n+1} that diverge from a node in row_n and the number of nodes in row_n that converge into a node in row_{n+1} a text-based representation of the crochet pattern can also be exported by the user.

Although the computational approach to generating crochet patterns closely follows the approach detailed in our previous work, numerous changes were made to the script to address various issues we have identified. One major intervention to the script was to implement the algorithm in IronPython to enable more efficient computation of the crochet pattern. This was achieved mainly by switching to a dictionary-based connectivity graph which enables efficient storage and lookup of each individual node as opposed to geometrically calculating the number of lines connected to each node. In addition to computational efficiency, the other area of focus was to improve how the generated information is presented and communicated to the users. For this, a simple graphical user interface (GUI) was integrated into the script that allows users to preview and isolate the generated crochet pattern for (a) entire geometry, (b) a single branch and (c) single row (Figure 7). Additionally, exporting the text-based crochet pattern was also reworked allowing the users to select between a verbose or simplified version exemplified in Figure 8.

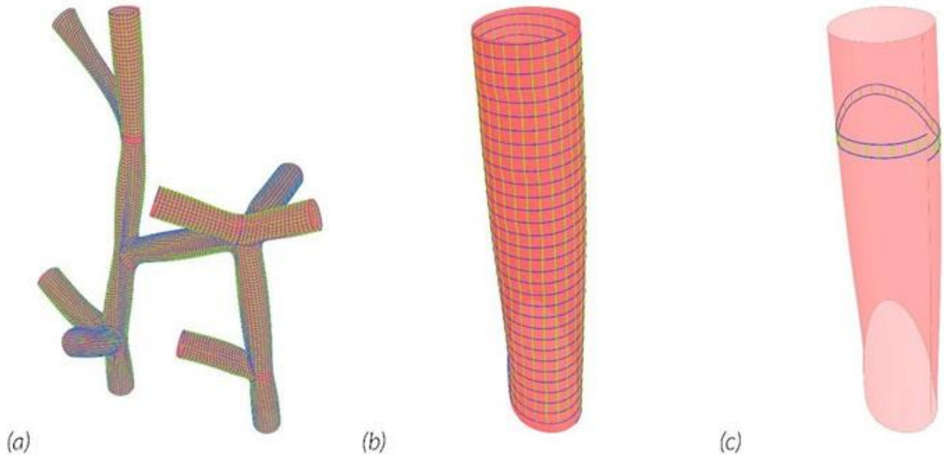

Figure 7. Computational stages of the pattern generation algorithm: (a) input surface, (b) generating the conformal spiral, (c) splitting the spiral into rows, (d) calculating crochet nodes, and (e) generating the graph network.

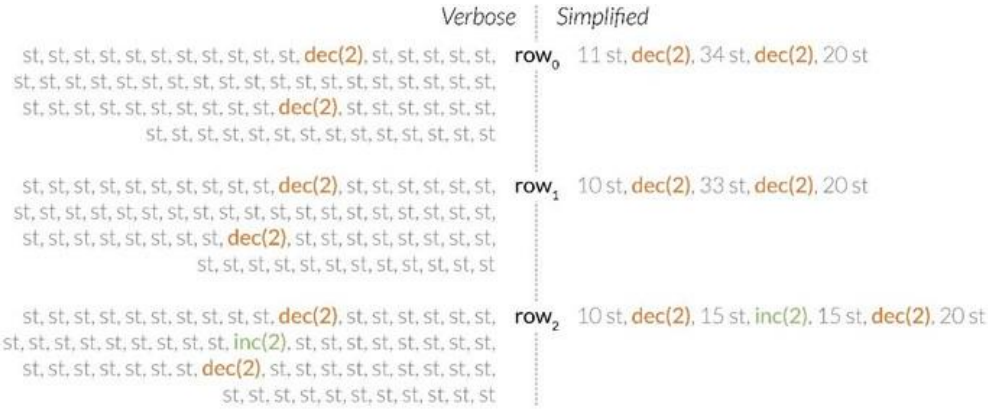

Figure 8. Computational stages of the pattern generation algorithm: (a) input surface, (b) generating the conformal spiral, (c) splitting the spiral into rows, (d) calculating crochet nodes, and (e) generating the graph network.

3.4. Proof-Of-Concept Crocheted Branching Structure

A proof-of-concept branching structure is crocheted by two students of architecture as part of the Advanced Digital Fabrication course at the Pennsylvania State University. The students generated the branching geometry shown in Figure 7a following the computational framework outlined above, for an exhibition to showcase various works from the course. Figure 9 shows the final crocheted structure as part of the course exhibition. The students first crocheted 10-stitches-by-10-rows swatches. The dimensions of these individual swatches were used as the inputs of the crochet pattern generator algorithm to generate individualized crochet patterns for each user. This way, the students were able to each crochet seven components based on their individual inputs while maintaining the dimensions and form of the digitally designed branching geometry. These components were crocheted together, filled with polyester fibers, and attached to / placed within acrylic boxes via crocheting. Both students had little experience in crocheting. They reported that they had spent around 1 hour crocheting each component, totaling around 7 hours of collective work to crochet the branching structure. The students also reported that the text-based crochet patterns were easy to follow, along with the digital interface that visualizes the stitches on each row.

Figure 9. Proof-of-concept crocheted prototype as part of an exhibition and a close-up view.

4. DISCUSSION AND CONCLUSION

This paper's focus is on the expanded computational framework that allows the users to generate individual crochet patterns for parametric branching geometries and the user interface developed to allow easy tracking of the stitches and rows on each component. While the components of the branching geometries can be crocheted by a single user, it is also possible to have different users crochet the components. In an upcoming publication, we will present the process and outcomes of an online design research workshop that we conducted with 20 participants from different locations around the world who collectively designed a branching structure and individually crocheted its components. This shows that the computational framework outlined in this paper can be used as a collective and distributed crocheting platform that allows the creation of large-scale crocheted artifacts.

Both crocheting and knitting are sustainable soft fabrication methods. Instead of ending up in landfills, the artifacts created through crocheting and knitting can be unraveled and yarns can be reused to generate new artifacts. Construction industry can also benefit from the circularity of these fabrication techniques. Both crocheting and knitting can be used to create lightweight tension structures and flexible formworks in architectural scales. While there are prominent examples of such applications in architecture with knitted textiles, crocheting as an architectural soft fabrication method is not explored yet. This is partly due to the possibility to automate knitting with industrial knitting machines. Industrial knitting machines that automate the knitting process can knit large and complex surfaces at once. However, there is no crochet machine developed to date to automate the crocheting process, and all crocheted artifacts are currently hand made. One reason behind this is the difficulty of simulating the complex and simultaneous hand movements necessary in crocheting stitches, so that it can be replicated by a machine. One possibility of automating the crocheting is through the integration of robotic arms in the process. We believe our research on computationally generating the crochet patterns can inform the robotic automation of the crocheting process.

Another future goal is to develop an open web-based user interface that can allow users who do not have access to (or are not proficient in) CAD software to easily generate 3D forms and obtain custom crochet patterns. Similar platforms exist to generate custom g-codes for FDM printing and paste extrusion (i.e. Potterware, SliceUp). This way, crocheting can become an alternative way to precisely transition from the digital to the physical without relying on digital fabrication tools.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

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WHAT MAKES A STREET WALKABLE? A DATA ANALYTIC APPROACH TO INVESTIGATING WALKABILITY FACTORS

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ABSTRACT

Walkability is a hot topic for variety of disciplines, as well as everyday walker. It affects the health, the environment and the liveliness of our neighbourhoods. Walkable streets are necessary for a better lifestyle and sustainable planet. The problem with walkability is that we still don't have a general understanding of the concept. Every study differs in the way they define walkability, thus making walkability a subjective topic. However, the subjectivity causes contradiction in science. In this study, the aim to answer the question of what makes a street walkable by using a data analytic approach. The features used in other studies, as well as new attributes specific to this study, were investigated. Street images were used to extract data. The data was divided into nine categories: Street, Sidewalk, Obstacles, Urban Blocks, Amenities, Transportation, Attractiveness, People, and Vehicles. Data collection was carried out by measuring physical attributes through Remote Sensing images in QGIS, visually analyzing qualitative attributes with Google Street Maps/View and double checking data in Open Street Map Overpass Turbo API. Attributes were translated into scores and normalized where possible. Mutual Information Matrix and Correlation processes were conducted in Rapidminer. The attributes were processed in relation to overall assessment of walkability which was defined with personal rating. As a result, Mutual Information and Correlation matrices are useful in figuring out the relationship and dependencies between different attributes. Applying data analytics to a more comprehensive dataset will help identify the global factors of walkability.

Keywords: Walkability, Data mining, Correlation, Mutual information

1. INTRODUCTION

Walkability has been a topic of interest for the past 20 years. Even though it may be considered an urban design problem at its core, walkability concerns many others from different disciplines from health experts to sociologists; most importantly, the everyday walker. Walkable streets are more than an indicator of healthier lifestyles and livelier neighbourhoods. It provides solutions to the greater environmental problems. Jeff Speck emphasizes that living in walkable cities is greener than living in a sustainable gadget filled house [1]. That's one of the many reasons walkability is crucial to understand and apply to our streets.

The problem of walkability is the lack of general consensus on what it is really. Each study identifies and explains walkability depending on the properties they deem more relevant; physical, environmental, social, and such. However, in the absence of a general definition, studies start to contradict each other. Each study presents valuable contributions to what makes a street walkable, yet they may be in disagreement [2]. Krambeck proposed a global walkability index in a graduate thesis [3]. There are studies that acknowledge the issue from the pedestrian viewpoint [4]. Another study points out that usually the macro-level characteristics (urban blocks, zoning, density) are studied, neglecting the micro-level characteristics (sidewalks, trees, furniture) [5]. Walk21, a walking movement organization, defines the reasons why people avoid walking in certain streets and to some locations as heavy traffic, crime rates, street cleanliness, lack of amenities, quality of pavements, and street lighting (https://walk21.com/). However, it is not possible to deduce walkability to only economic factors (i.e. shops, or malls). Walkability of a street also depends on well-connected streets,

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buildings that are human-scale, building density and population, wide sidewalks, trees and greenery [6].

Different studies have used variety of metrics to identify the walkability of streets on a scale. Walkscore (https://www.walkscore.com/) is one of these metrics which considers block length, intersection density, transit score, bike and rail stops, errands, culture, grocery, park, dining, school and shopping scores. Walkscore awards points according to the closest amenities. But it doesn't differentiate amenities. It also doesn't introduce sidewalks, cars, lanes or crime. Walkonomics looks at the issue from a different perspective: Photos shared on social media. It compares the photos and the rated street segments. This comparison proves further the idea that fewer cars equal more walkability. Crime areas are photographed less at night. There is a positive correlation between photos tagged with "'sidewalk', 'clean street', 'tree' and 'architecture'" and pedestrian friendly streets [7]. More studies try to identify and measure walkability with different methods: Measuring qualitative aspects of walkability with the help of an expert panel [8,9]; evaluating walkability aspects selected by experts by the ratings of pedestrians [10]; combining different methods for easier and more accessible data analysis [11]; integrating GIS-based methods [12,13].

The studies summarized suggest the importance and the relevance of walkability. However, as can be seen from the limited literature mentioned above, there is still no unity in its definition. Walkability is not in dictionaries like Merriam Webster and Oxford. It is not found in dictionaries of other languages, such as Turkish. The subjectivity of walkability remains. This study asks the still unanswered question: What makes a street walkable? By utilizing data mining methods such as mutual information and correlation matrices, the study aims to answer the following questions:

-What features of walkability affect the personal assessment?
-What is the relationship between walkability attributes with regards to personal assessment?
-Which walkability attributes can be the defining factors of walkability?
-What kind of data can be extracted from street images?

2. MATERIALS AND METHOD

In order to answer the data analytic questions, the study follows a process of data collection, preparation, processing, modeling, and interpretation (Figure 1). Firstly, the attribute data was designed according to the literature review. General attributes used in most of the studies and more customized attributes such as "store owners" were used. Data was collected by measuring physical attributes through Remote Sensing (RS) images in QGIS, which is an open source geographical information system software, visually analyzing qualitative attributes with Google Street Maps, and double checking data in Open Street Map Overpass Turbo API. After a normalization process, Mutual Information Matrix (MIM) and Correlation Matrix (CM) processes were conducted in Rapidminer. MIM and CM reveal positive and negative relationships between each attribute, and their dependencies.

Figure 1. Data analytic process

Deriving from the range of studies mentioned in the previous section the walkability data were gathered under nine categories: Street, Sidewalk, Obstacles, Urban Blocks, Amenities, Transportation, Attractiveness, People, and Vehicles. Each category was also divided into different attributes. Personal rating of walkability was described as the overall assessment which made up the label attribute that other attributes would be associated and compared to. Since there were a lot of attributes, numeric data was normalized to [0, 1] and a scoring system was introduced where possible. This proposed method was applied to the streets of Izmir as case study. In the scope of this study, there were 70 instances and 12 attributes. Instances refer to individual examples which are the streets selected for the case study. Attributes are the characteristics of an instance and they are either nominal or numeric. The attributes of each walkability category are shown in Table 1, which reflects the list of attributes before any reduction. As this study covers a very limited dataset of 70 instances, attributes were condensed into 12 by rescaling, normalization and/or scoring. Some attributes are left out as they had no impact in this study. Attributes indicated in italics indicate temporal data: Data obtained at a specific date and time. Overall assessment is the label attribute. The twelve attributes are Sidewalk Width Normalized, Crossing per 100m, Obstacle Score Normalized, Height category, Facade transparency, Amenity per 100m, Attractiveness Score, People Score Normalized, Store Owners, Lane Width Normalized, Cars, and Bikes.

Table 1. Walkability data categories and attributes

Street	Name Length *Walk duration*	id How long is the street? *meters* How long does it take to walk the whole street? *minutes*
Sidewalk	Width Crossings (per 100m)	What is the width of the sidewalk? How often is the sidewalk cut by other streets?
Obstacles (Score)	*Trash* *Barriers* *Store Stuff* *Street Vendors* Signage *Parking on Sidewalk*	Are there any trash or trash cans? Are there any constructions, road cones, parking signs? Are there any tables, chairs, umbrellas? Are there any (mobile) street vendors? Are there any store signage, advertisements, and traffic signs? Are there any cars occupying the sidewalk?
Urban Blocks	Height Façade Transparency	What is the average floor count of building blocks? transparent, semi-transparent, non-transparent
Amenities (per 100m)	Education Retail Medical Financial Social Leisure	Schools, university, learning centers Convenience stores, markets, shops Pharmacy, hospital, clinics Banks, post office Barbers, gym, library, cinema, restaurants, cafes Parks, Squares
Transportation	Bus stops Metro/Tram Station	How many bus stops? How many metro/tram stations?
Attractiveness (Score)	Trees *Shade* Lighting *Cleanliness*	Are there any trees? Are there any shading elements (tents, big trees)? Are there any street lights? No trash on the ground. Clean or not?
People (Score)	*Age* *Action* *Store Owners*	Young, Adults, Seniors walking, stalling, shopping, eating, sitting, playing Are there anyone we can identify as store owners?
Vehicles	Lane Width *Cars* *Bikes*	What is the width of the lane used by vehicles? Are there any cars? Are there any bikes?
Overall Assessment	Personal Rating	walkable (5) to non-walkable (1)

Transportation attributes were not used as there was no specific difference between the instances. Street length and walk duration were left out due to not being defining factors in this case. Obstacles, amenities, attractiveness and people attributes were scored according to their subcategories. Crossings and amenities were rescaled to "per 100m", and Obstacle Score and Attractiveness Score were calculated as one point for each true (i.e. if there is trash, then true. Add 1 point.). People Score was calculated as the number of age groups multiplied by the number of actions. For example, if there were two age groups on that street (young, adults) and there were six different activities, two was multiplied by six. Building heights were labeled in three categories: Lowrise (1m to 3m), Multistorey (3m to 7m), and Midrise (7m to 9m). After all the categorization and normalization were finalized, the data was processed and modeled in Rapidminer (Figure 2). All the attributes with relation to overall assessment (of walkability) were processed with CM and MIM; the attributes of Amenities, Obstacles and Attractiveness individually with relation to overall assessment (of walkability) were processed further with MIM.

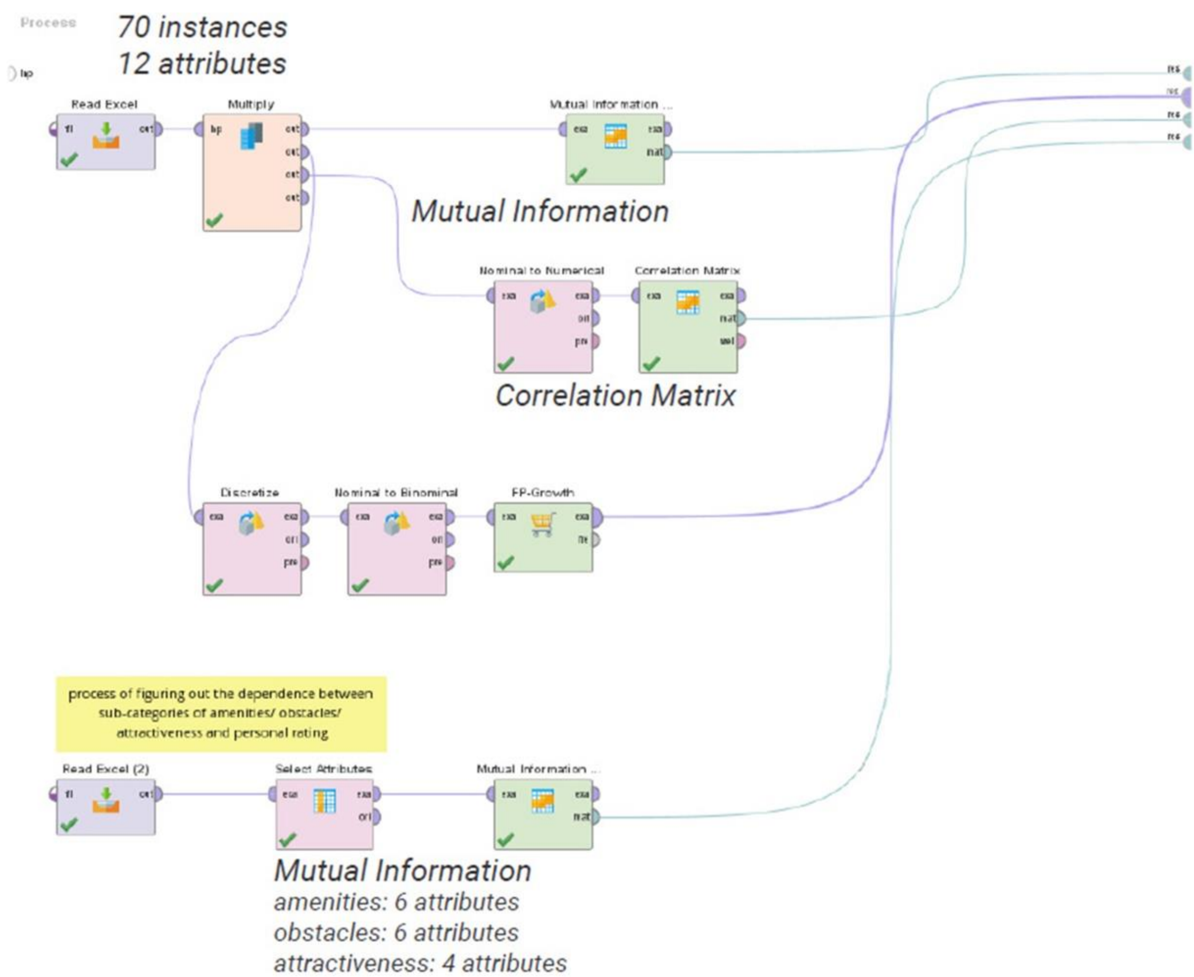

Figure 2. Rapidminer process

3. RESULTS

Results of MIM suggests that lane width, obstacle score, sidewalk width, amenity per 100m and people score tell us the most about personal rating of walkability (Table 2). Other relations uncovered with MIM show that sidewalk width is linked to obstacles and amenities, obstacles more linked to amenities which can be deduced as more amenities mean more store stuff on the sidewalk. Amenities are also linked to lane width, and this tells us that the larger streets may attract more amenities. Façade transparency is linked to amenities the most and it can be explained by amenities having a glass façade where private buildings such as housing don't allow us to peek inside. "Store owners" is an attribute that is interesting to analyze, especially in Turkey where shopkeepers like to spend time socializing outside their shops. Consistently, this attribute is related to amenities and façade transparency.

Table 2. Mutual information matrix based on personal rating of walkability.

Attributes	Personal Rating
Lane Width Normalized	0.653
Obstacle Score Normalized	0.626
Sidewalk Width Normalized	0.611
Amenity per 100m	0.564
People Score Normalized	0.506
Crossing per 100m	0.435
Cars	0.296
Attractiveness Score	0.258
Bikes	0.209
Façade Transparency	0.206
Store Owners	0.131
Height category	0.117

Results of CM confirm the results of MIM. When MIM and CM are compared side by side in terms of personal rating of walkability, the conclusion is that sidewalk width, amenity and people have positive correlation and more dependence; car-free streets, bikes and transparent façade have positive correlation with less dependence; lane width and obstacle score have negative correlation with more dependence (Figure 3).

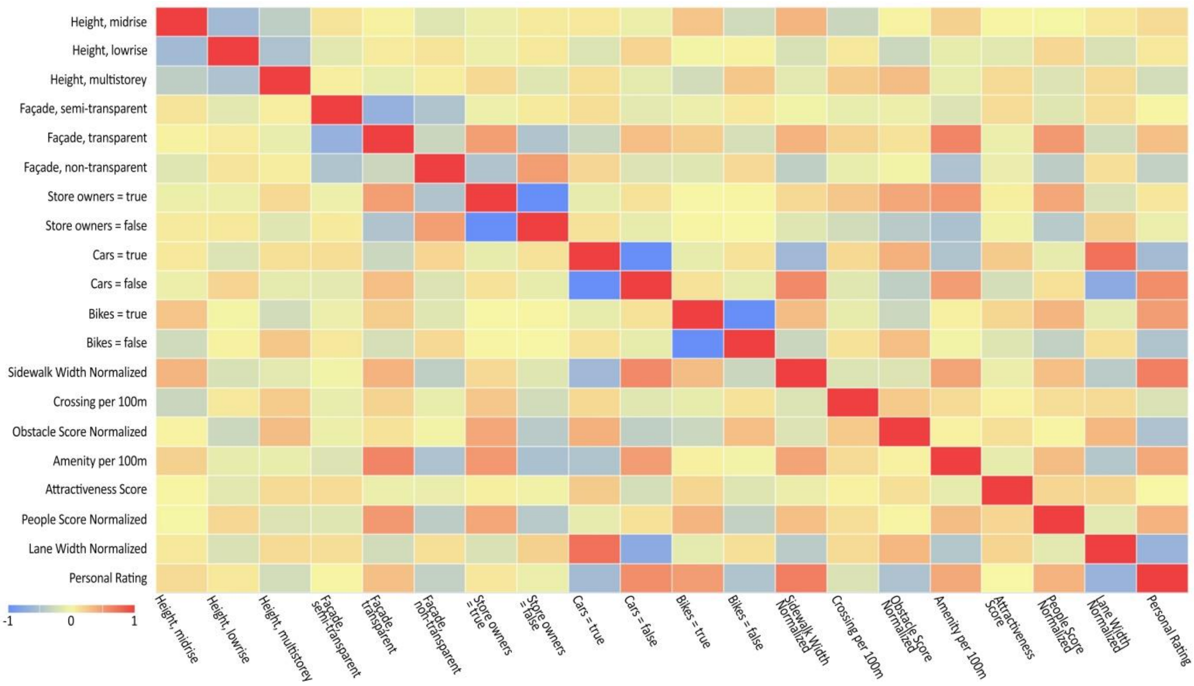

Figure 3. Correlation matrix where blue indicates negative and red indicates positive.

The dependence between the sub-attributes of amenities shows that there is no significance in the kind of amenity there is on the street with regards to walkability. Only retail and financial attributes show stronger dependence which may be speculated as more shopping equals more need for cash or banks tend to cluster around economically active areas (Table 3).

Table 3. Mutual Information Matrix of amenities

Attributes	Personal Rating	Educational	Retail	Medical	Financial	Social	Leisure
Personal Rating	2.228	0.327	0.380	0.270	0.332	0.341	0.227
Retail	0.380	0.243	2.272	0.511	0.774	0.433	0.236
Social	0.341	0.317	0.433	0.327	0.595	1.923	0.181
Financial	0.332	0.366	0.774	0.594	2.014	0.595	0.231
Educational	0.327	1.376	0.243	0.257	0.366	0.317	0.085
Medical	0.270	0.257	0.511	2.201	0.594	0.327	0.068
Leisure	0.227	0.085	0.236	0.068	0.231	0.181	1.242

In terms of obstacles; parking on sidewalks, trash and signage have a more significant effect on walkability rating (Table 4). Attractiveness, on the other hand, relies more on cleanliness (Table 5).

Table 4. Mutual Information Matrix of obstacles

Attributes	Personal Rating	Trash	Barriers	Store Stuff	Street Vendors	Signage	Parking on Sidewalk
Personal Rating	2.228	0.363	0.175	0.033	0.171	0.323	0.458
Parking on Sidewalk	0.458	0.149	0.194	0.009	0.058	0.223	0.913
Trash	0.363	0.844	0.054	0.021	0.025	0.075	0.149
Signage	0.323	0.075	0.099	0.004	0.008	0.722	0.223
Barriers	0.175	0.054	0.692	0.054	0.013	0.099	0.194
Street Vendors	0.171	0.025	0.013	0.041	0.913	0.008	0.058
Store Stuff	0.033	0.021	0.054	0.627	0.041	0.004	0.009

Table 5. Mutual Information Matrix of attractiveness

Attributes	Personal Rating	Trees	Shade	Lighting	Cleanliness
Personal Rating	2.228	0.097	0.088	0.072	0.158
Cleanliness	0.158	0.053	0.003	0.084	0.881
Trees	0.097	0.863	0.024	0.089	0.053
Shade	0.088	0.024	0.371	0.010	0.003
Lighting	0.072	0.089	0.010	0.422	0.084

4. CONCLUSION

As the results show, many features affect the personal assessment of walkability. According to the data analytic process lane width, obstacles, sidewalk width, amenities and people on the street affect walkability significantly more. Comparing the attributes that have positive correlation with personal assessment, bikes and façade have less dependence whereas sidewalk width, amenities and people have more dependence. The relationship between walkability attributes is more intricate. Both MIM and CM uncovered different relationships between attributes in the scope of this study as mentioned in results; however, larger dataset might help unpack these relationships even more. The results show that lane and sidewalk width notably affect walkability, yet they can't be labeled as defining factors. Many other attributes have an impact on the walkability assessment. Amenities, shade, cleanliness might make a street with wider lanes more walkable compared to a street with ideal lane and sidewalk width with nothing to do and nowhere to rest. Data in this study was mostly extracted by simple observation of street images. It was possible to find out many features of a street via images in a plot study like this. As humans we can recognize and understand images, categorize shapes and things, make judgments regarding the image in question. However, bias and interpretation might hinder the data extraction process by human gaze. Computer vision will be better suited for decreasing bias and speeding up the process in a larger dataset.

Walkability is subjective. Attributes change and/or transform in every other study. By using data mining methods, as seen in this study, we are able to figure out the relation between our understanding of what walkability is and its characteristics. In order to work with as many attributes as in this study, we need a huge amount of data. More data will help uncover more relations under a complex phenomenon such as the city. It will be easier to expose different dimensions of walkability. But simply more data is not the best way to go. More data may also cause noise which is a problem that requires more time spent on preparation and preprocessing. As the amount of data increases, the need for automation rises. In terms of extracting data from images like in this study, automation where possible (such as image processing and recognition) will make the data collection and analysis easier than manually filling the data table.

This is a pilot study which gives us clues on how to combine data mining methods with the subjectivity of walkability problem. The aim is to develop this study further with more attributes that haven't been included due to limitations in data collection and construction. The attributes planned to be include are listed, but not limited to, as follows:
- Quality of pavement: Height, material, no hazardous pits.
- Slope of the street: Is it too steep to walk?
- Children: Is there a correlation between walkability and the number of children spending time / playing on the street?
- Stray dogs: Despite being members of our communities, sometimes a large number of dogs is scary for many people.
- Tram lines: Just because a street is closed to car traffic doesn't mean there is no danger from other means of transport.

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CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

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COMPUTATIONAL ANALYSIS FOR DESIGN DEVELOPMENT EVALUATION IN SPATIAL PLANNING

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ABSTRACT

The influence of new technological software on architectural design is increasing with every passing day. This led to new horizons discovery in spatial analysis and design interpretation and extended by engaging different techniques based on computational design and human-computer interaction. Throughout the architectural design process, decision-making on spatial performance parameters such as visibility, density, and building typology is frequently taken by examining a limited number of materials. They are conventionally optimized by employing repetitive experimentations without systematically evaluating the complete range of potential designs and their efficient outcomes. A computational design analysis approach of spatial morphological structure based on several indicators is presented in response to this challenge. This research compares contextual spatial analysis with computational methods and determines the consistency of Eskisehir technical university master plan expansion mechanisms through the relationship between layout and spatial arrangement, connectivity and accessibility, and built area and open space of the university map in two different periods (2005/2020). For density measurements, Ground Space Index (GSI), Floor Area Ratio (FAR), and Open Space Ratio (OSR) calculations in urban spatial planning are analyzed. Furthermore, the Isovist analysis (Attractiveness, Extent of observation, line of orientation, and arrangement) and their visual quality was examined using the logical interpretation approach. The collected visual and numerical data show that the visual quality of the observer's full view, as seen from the center of the university campus master plan, is directly related to the open space and built environment. The visibility and density characteristics of the university campus master plan showed that these analytical techniques are very responsive to the design limitation and context requirements. The presented application has evaluated the visual aspects of each of the university campus maps to deliver a technique to the designers so that they may implement their requested visual characteristics in future design expansion.

Keywords: Computational analysis, Spatial planning, Architectural design, Development mechanisms, Campus master plan

1. BACKGROUND

The expansion of urban space, which ultimately determines a city's sustainability, is a critical issue for space planning and urban management. Growing areas have become denser, yet they have been planned inefficiently, resulting in abandonment and land transformation. Enormous data may be synthesized into significant information via spatial analysis. These data incorporate properties such as a big frequency, a variety of operators, and a temporal sequence [1, 2].

The master plan of the university campus presents a leading outline of expected campus growth and defines a set of architectural guidelines that are meant to direct design decisions in a way that adapts to the university's changing needs. The initial space layout concept is an important first step in any architectural design process. According to many existing examinations, the major master plan characteristics that usually impact decision-making are dependent on the layout and spatial arrangement, connectivity and accessibility, and built area and open space. These are generally studied by engaging conventional spatial analysis. Recently, multiple studies on university campuses aim to increase spatial

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growth capacity, optimize the successful outcomes of space creation, and maintain the validity and availability of an appropriate density of open space and built area on campus.

The design of urban spatial forms is an interplay of qualitative and quantitative planning based on urban transformation objectives [3, 4]. It is critical to disclose effective and sustainable planning that permits the assessment of the effects of spatial change [5, 6, 7]. The advantages of this operation include higher quality of living, social connections, and neighborhood relationships, improved pedestrian and biking activity, an enhancement in major sectors, and the multifunctionality of the urban area [8]. However, there is no quantitative analysis of the integrity between urban spatial form and planners' spatial design planning purpose depending on the planned system [9, 10]. Contemporary computational design competencies permit cutting-edge data analysis, interpretation, and the emergence of complicated forms and spontaneous evolving novel processes as well.

Accordingly, this research examines Eskisehir Technical University campus master plan aiming to decode university expansion requirements and cooperate with design specifications to direct the development plan decisions. It investigates a process by comparing multiple maps from different periods (2005/2020) to evaluate the expansion of the campus master plan. Furthermore, the analysis aimed to better understand how this university campus master plan could evolve and expand and the main spatial elements and environmental components that control its evolution mechanism. The in-depth analysis of the campus master plan engages two different techniques, “Contextual Analysis” and “Computational Analysis”. The analysis fundamentally tends to answer these questions: What main master plan elements have a key role in directing the expansion? How do the built area and open space interact during spatial development?

In order to efficiently respond to those questions, contextual and computational analysis techniques were involved by exploring design problems and environment requirements. The gathered data were classified into several categorical dimensions based on the research intents. The assessment process of layout and spatial arrangement, connectivity, accessibility, built area, and open space was the emphasis of contextual analysis. Whereas computational analysis allowed for the inquiry of density and visibility measurements through several indicators and techniques such as GSI, OSR, FAR variables [11], and Isovist visibility analysis [12], using the computational design plugin Grasshopper inside Rhino software.

2. CASE STUDY AREA OVERVIEW

Eskişehir Technical University (ESTU) is situated in the Anatolian region of Turkey, exactly in the city of Eskişehir. The foundation of ESTU was back in 2018 after its detachment from Anadolu University. The main university campus “Iki Eylül”, has a total area of 4710 decares, including the land assigned as the area of future expansion. It has a land area size of 4.3 million square meters and a campus area of 114,034.47 square meters. The functions, approximate sizes, and interconnections between the open-closed spaces of the spatial elements that will be built in addition to the existing buildings and amenities have been identified. Simultaneously, the active campus plan is 574 000 m2, and the campus extension area is planned to be 454000 m2 (Figure 1.). Based on the proposed development plan, the campus is arranged to be expanded toward the north, away from Hasan Polatkan Airport on the southern side, along with the Muttalip highway on the eastern wall, and the transportation axis that runs parallel to the western wall.

Currently, the university is trying to put in place again its spatial identity with a contextual and environmental approach. The relationship between different spatial parameters is required to be well arranged. The density of land-use and build/ non-built areas should be redefined according to the plan development proposed within the parcels organization.

This analysis describes the characteristics of the environmental and spatial functions, which are intended to be sustainably carried out in the "İki Eylül" Campus between 2020 and 2035, and the resource requirement needed for the study. It is aimed to prepare and implement the spatial limitations and context requirements within the early formulation of the generative design system. The development plan is prepared according to future spatial planning and existing design parameters of sustainable campus concept including a requisite target.

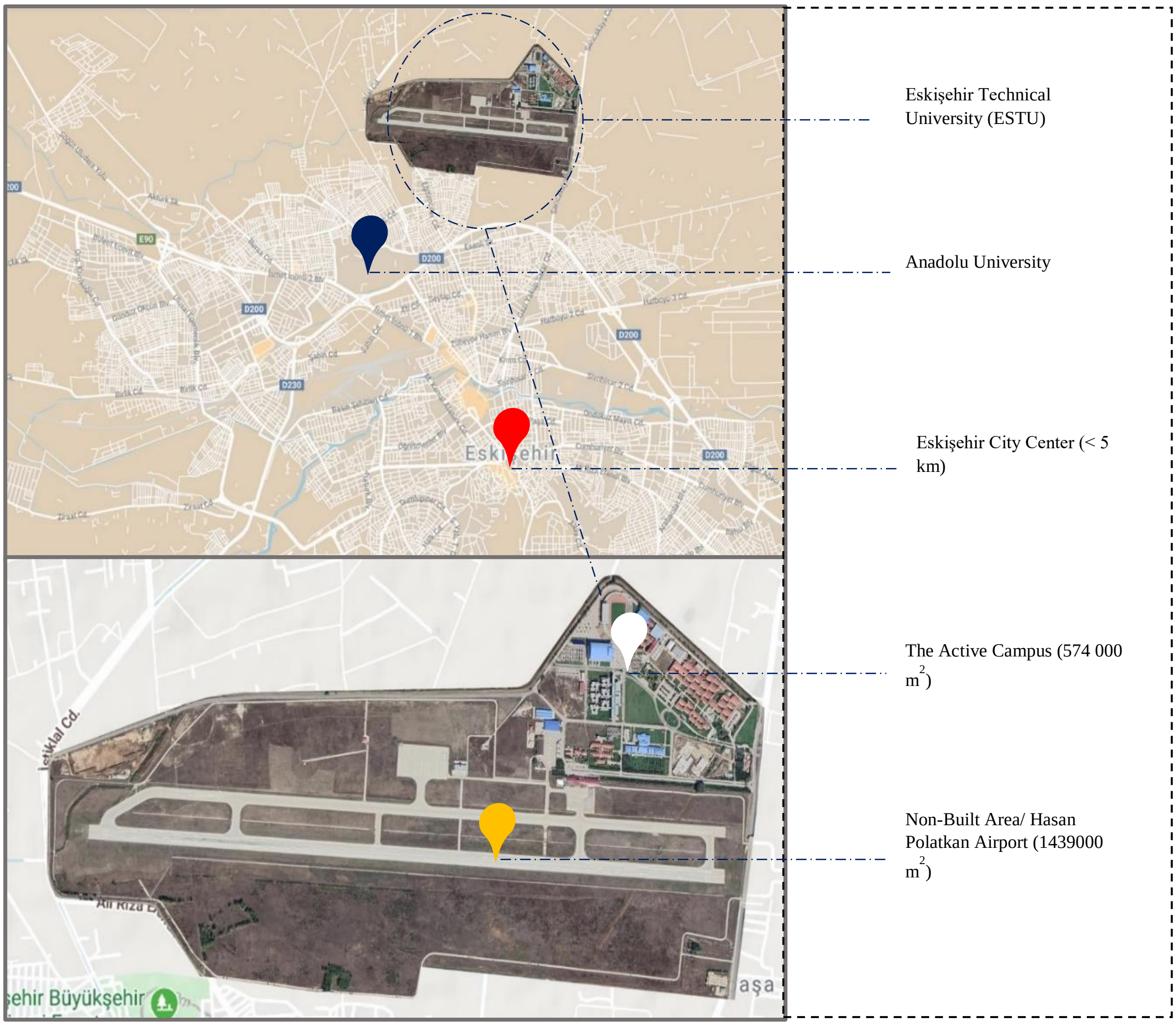

Figure 1. ESTU location in the city of Eskişehir map. (Source: by the author).

Getting a clear overview of the design elements of the university campus development plan makes the following analysis phases more oriented. Information about the expansion intent and the future crucial mechanisms of development comes in the first generative design system parameters. Generally, layout and spatial arrangement, connectivity and accessibility, and built area and open space are the most effective elements assigned by the plan. Those elements are more explored engaging different analyses discussed in the next sections of the research [13]. Recently, the university aims to increase the land's growth capacity and optimize the successful outcomes of space creation and also maintain the validity and availability of an appropriate density of open space and built area on campus.

3. METHODS AND APPLICATIONS

Throughout the architectural design, decision-making on spatial performance parameters such as visibility, density, and building typology, is frequently taken by examining a limited number of materials, optimized by repetitive experimentations, without carefully evaluating the complete range of potential designs and their efficiency outcomes [14]. To systematically investigate the influence of spatial planning and the associated variable values, the study engaged different analysis methods. The analysis would not claim to give specific proposals to campus decision-makers or designers; instead, it helps to assess, classify and comprehend the existing data in reality as well as provide a conceptualization forward for research on the related subject. It employs the comparative research method [15] to focus on architecture features and concerns responding to the improvement of campus infrastructures and mechanisms of integration. Special focus is given at particular points in time to the transformations of the master plans of the university, the map in 2005 compared to the map in 2020 (Figure 2.). The in-depth analysis of the campus master plan engages two different techniques, “Contextual Analysis” and “Computational Analysis”. It is through examining these master plans in an integrated and comparative way that we would be able to consider such discussions as the key that determines the main parameters required in future generations. The contextual analysis is based on a qualitative assessment of the plans and observation-based interpretation of the needed data and information. Whereas, the computational analysis uses a quantitative assessment by engaging several parametric techniques to seek to explain various elements of the research subject. For this experiment two different techniques of analysis have been performed, density analysis and visibility analysis.

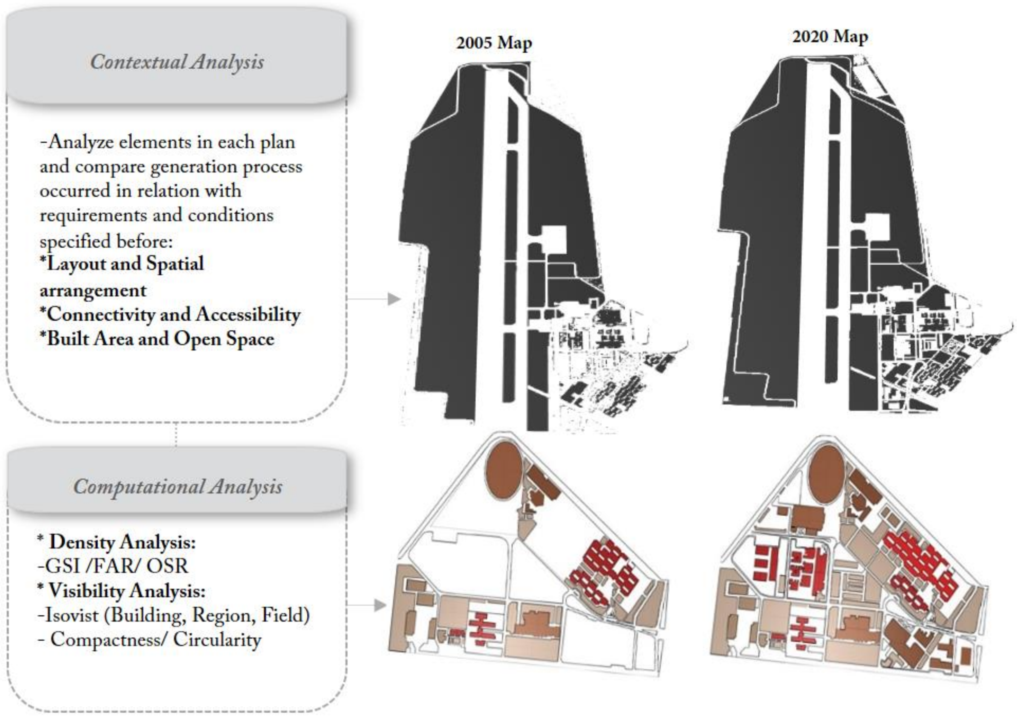

Figure 2. Contextual analysis and computational analysis aspects for the data collection part (2005/2020 Maps). (Source: by the author).

It is believed that density analysis is one of the most used techniques to recognize spatial development [16]. It allows measuring different indicators considering open space partition and building volume. This technique engages different parts of the urban fabric such as parcels, footprints, blocks and streets to measure density in a specific area. For that reason, many other analytical applications could be anticipated in further advanced measures. Frequently a ratio between different techniques can be also engaged to comprehend relatively the performance between several elements. Some research examined how each street is connected to the network in terms of integration and direction variance [17]. While they proposed another approach to analyzing density by using different variables such as GSI, FAR, and OSR [11]. The Ground Space Index (GSI), measures buildings' footprints in a specific area by dividing the total built footprint area by the base land area. The outcomes are usually visualized through ground-based drawings. The Floor Area Ratio (FAR), essentially focuses on calculating the built area density in combination with the building's floor area existing in the same environment divided by the general base land area. It is known also as the indicator of land-use intensity that aims to understand the effect of volume features on a specific site. The higher level of ratio signifies a high number of floors per area. The Open Space Ration (OSR) is focused on measuring the existing open space through a specific area. The ratio of open space is calculated by dividing the non-built area by the floor area. It is also engaged in measuring the indicator of an area's spaciousness, daylight measurements and ground levels.

Visibility analysis is one of such measurement tools which refers to a set of points visible from a given vantage point. In Hillier and Hanson's experiment, the space is viewed as a series of axial lines that form the longest view lines in a convex space. Their study indicates that the context of space has employed Isovist analysis to interpret visual perception. The communication of space comprises a set of tools for analyzing spatial systems using simple path and node diagrams [18]. In the campus mater design, Isovist indexes such as area, degree of displacement angle, maximum radius boundary, and enclosure are very practical. This allowed them to assess some of the environment's basic dimensions, characteristics that their implicit or explicit preconceptions adopted to establish a more basic perception and a more comprehensive representation of the environment. As a result, the space is defined as a collection of accessible points extending from a single point in the same area [19].

Within this section of the analysis, attempts have been made to measure the qualitative aspects of the environment and different findings have been obtained. This type of analysis requires a careful calculation of different parameters such as compactness and circularity [20]. The complex relationship between the built area and open space in the campus master plan is reflected by this analysis. To have desirable results a large amount of computing time should have been carried out in both formulation and application of the parametric model. The visualization of spatial visibility is performed by colors referring to different results. The visibility analysis focused as well on different Isovist applications, it was instructive to see the closeness of the plans as well as the openness of the areas and how they behaved. These applications are mainly used to calculate the visibility of the buildings and their relations with the open spaces [21].

4. COMPUTATION AND ANALYSIS IMPLEMENTATION

The main intention of this part of the research is to clarify the university campus structure with the potential for sustained expansion, carrying the basic framework for the campus's favorable development. The dependence between layout and spatial arrangement, connectivity, and accessibility, built area and open space of the university map in two different periods are used to compare contextual spatial analysis with computational methods and determine the consistency of Eskisehir technical university master plan expansion mechanisms.

4.1. Contextual Analysis

Studying the development of a master plan over time will allow exploring the various mechanisms that affect its formulation [22]. For this aim, an in-depth qualitative analysis of the two different master plans was carried out enabling us to concentrate on the specifics and suggestive complexities of how the campus reacted to various circumstances and environmental limitations. The contextual analysis explores the connection between the different spatial elements through ESTU University's master plans. In doing so, it has sought to investigate how the plan has evolved in relationship to density, street networks and building patterns.

4.1.1. Layout and Spatial Arrangement

The main campus layout was developed spontaneously as long as there was no clear development plan for its expansion. Its spatial arrangement is defined by a range of repetitive structures. The campus master plan is strongly representing the existing circumstances of the area. It is essential to explain, identify and encourage campus identity to build a clear sense of location [23]. Establishing a relevant layout for the campus area as well as the environment surrounding is a task that should be effectively accomplished. ESTU campus master plan is created with regions geographically restricted or self-identified with the same initial progress and expansion. It is not impressive that the 2020 plan layout does not differ extensively from the 2005 plan, except that a few more buildings have been constructed inside the boundaries of the empty predefined regions (Figure 3.). In the north, the plan expanded in the same formularization with slight changes in building patterns. The layout allows for alignment along the main axis, starting from the lower region of "Muttalip Bulvarı" to the northern area where there are a variety of important university functions (basically social functions). The pattern of expansion is maintaining the initial pattern that creates a focal point and a central dense environment with an appropriate distribution. Buildings placed in the north and northeast areas show the same patterns and look similar in several characteristics, thus highlighting an ideal continuity and a simplified identity of the master plan. Placing the main entrances of each building in all the regions away from the main street was also an investigation. This has created a boundary between the inside and exterior of separated regions with interconnection and thereby enables the campus inward centralization. The spatial arrangement of the campus master plan does not anticipate sustainable growth guidance proposing for future spatial expansion and generation.

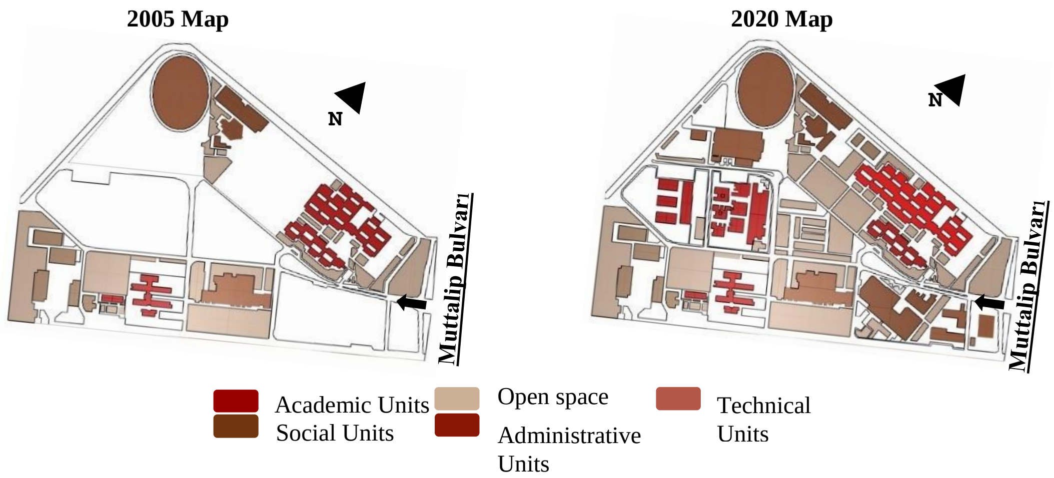

Figure 3. Layout and spatial arrangement of the university campus master plan (2005/2020 Maps). (Source: by the author).

4.1.2. Connectivity and Accessibility

The campus master plan is segmented with intersections between a series of the main axis and sub axis which permit street networks to be one of the essential elements of spatial connectivity. The main street as a core of the plan is dividing the area into two main parts north/south. It remains the same in both maps while other street networks disappeared and some others emerged. The main street has major importance and centrality which could be seen from its connectivity with other street networks and that makes it a geometrical force to areas division. The creation of a significant linear sub axis connecting the main street and the north part along with its boundary features progressively declining lines to the South allows the master plan to be more accessible. Also, every part of the plan is properly identified by the circulation of streets and bypasses that describe the connection between the buildings and their surroundings in two different patterns (Figure 4). The plan establishes vertically high division paths leaning significantly to the right. They allow for external circulation of the area while setting the key buildings inside the circulation zone in a symmetrical plan and generate spatially different street network patterns. The street on the west-east side of the university serves as a basis for the campus, with small service streets connected to it. The most significant pedestrian spine existing at the campus is that of the northeast. In addition, the external pedestrian street specifically marks the boundary between the inside and outside of each section of the plan. The comprehensive public transport network also covers easy transport and bus lines within the same main street direction. Some parts adjacent to the main street were kept unplanned, visibly emphasizing different paths that entered the main street. Pedestrians and vehicles move in parallel in the same direction. This is what makes the quality of pedestrian routes across the campus don't respond to the general accessibility. Although the main entrance orients the street network and the distribution of the parcels and functions within the master plan, the accessibility is not effectively integrated as a key element in the expansion of the university campus master plan. Furthermore, the relationships between various parcels and functions are neither geometrically represented nor integrated to maintain campus continuity.

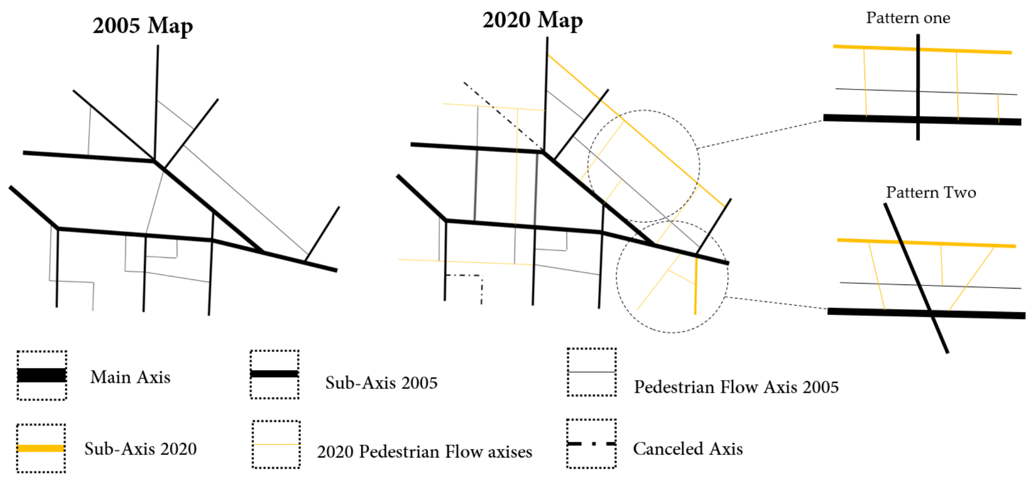

Figure 4. Connectivity and accessibility of the university campus master plan (2005/2020 Maps). (Source: by the author)

4.1.3. Built Area and Open Space

The university campus master plan was not fully built but somehow defined as an expression of randomization, which can be demonstrated by the grid system arranged in different locations without any expressive logic. The open space implementation and character are significantly presented as identification of the campus layout. The spatial arrangement was not a challenge towards uniformity but on the contrary in the creation of proportional distribution that connects the campus. The university master plan includes many open spaces, primarily in the campus core. It is providing a strong distinction between the north and the south, which highlights the central region. This refers to the spatial alignment of buildings around the main street, the layout of the plan in the north and the development of the eastern area where the main entrance is situated (Figure 5.).

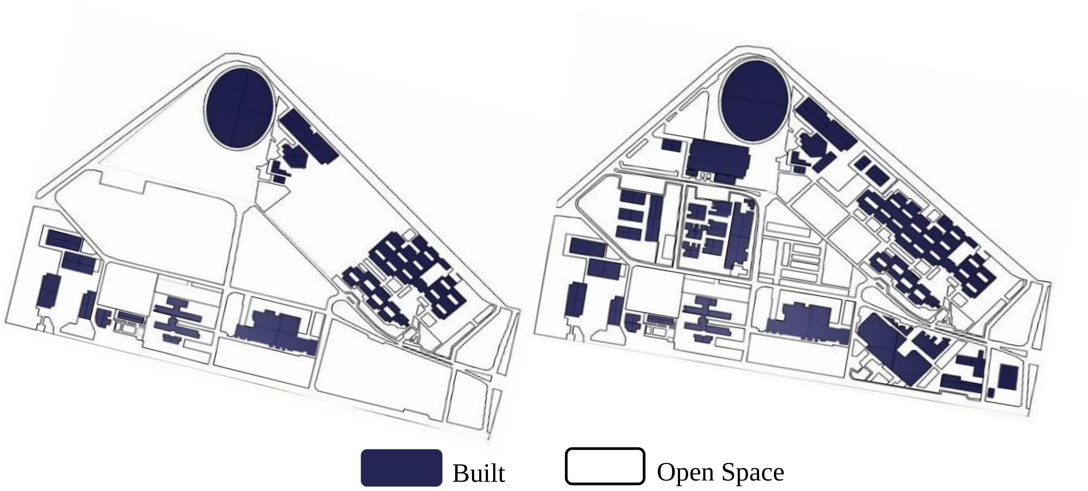

Figure 5. Built and Open Space of the University Campus Master Plan (2005/2020 Maps). (Source: by the author)

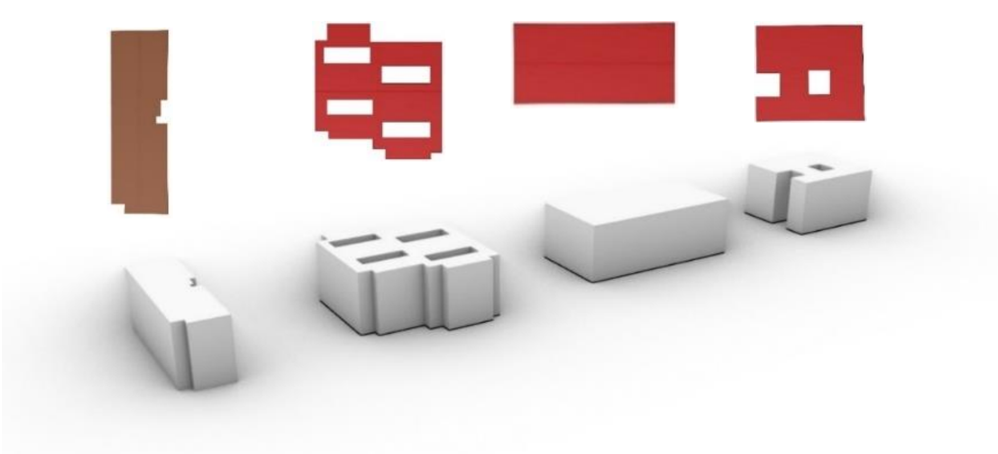

Figure 6. Buildings Design Patterns at the University Campus Master Plan (2005/2020 Maps). (Source: by the author)

The relationship between buildings, parcels and the street networks was a result of unplanned generation which called for a focus on the spatial typology. A significant built and open space proportion is presented in each of the northern and south-western regions of the campus. This combination reflects simultaneous campus components, interaction centers and a prosperous university campus social environment. The master plan for the campus proposes increasing growth rates to generate open space. This approach is retaining the same design pattern in almost all parts of the master plan. The buildings' designs are based on four main different patterns (Figure 6.).

4.2. Computational Analysis

Within this section of the research, an analysis of the two university campus 2005/2020 plans relied on computational techniques by measuring different features such as density, visibility compactness and circularity. It tries to explore the potential of the computational analysis methods to understand the university campus master plan development mechanisms and approaches. The computational analysis method is used effectively on the master plan scale to test various designs and their performance, but many challenges are presented while applying it on the real scale due to data calculation and parameters manipulation (24). Several difficulties in limiting inputs and more important specifying the time involved in the process.

The computational analysis demands qualified practical designers to determine success purposes based on the understanding available at each phase of the creation of a master plan and interpreting the implications of the land use, density and design choices on those aims into numerical and geometrical data. For this experiment two different techniques of analysis have been performed, density analysis and visibility analysis.

4.2.1. Density Analysis

Density as discussed previously plays a crucial role in the formation of university master plan development phenomena. The relationship between the built environment and open space is very important to understand the growth behavior and predict future alternatives for space generation. This analysis is based on considering those two spatial elements with each one's characteristics. The set of indicators is modeled considering the morphological properties of the elements. Spacematrix, as an analytical approach [11], parametrically represents urban topologies and comprises a three-dimensional reference system that allows for the assessment of variable values for structures of various geometries. Through this study, density analysis employs many components and functions using Grasshopper in Rhino to measure the necessary spatial parameters and presents the measurement findings in a graphical and comprehensible format, evaluates the spatial morphological structure, and highlights the limitations of urban organization structure. The integration of spatial syntax with computational interaction will support the examination of urban process changes.

Urban compositions cover different regions of the Spacematrix, allowing for the investigation of, on the one hand, well-known architectural features such as perimeter pattern buildings and area structures, and, on the other hand, the involvement that the completely separate factors play in the performance, density, and open space arrangement in this research case. The system is preconfigured by defining different parameters. On the X-axis is the ground space index, or GSI, and on the Z-axis is network density. The computational model's additional components are the open space ratio, OSR, and the number of floors. The building coverage of the master plan area is represented by GSI (GSI = F/A), where F represents the building footprint and A signifies the land surface which equals 574 000 m2. FAR identifies the relationship between total gross floor area and land area. Additionally, OSR could be computed using the variables FAR and GSI as OSR = (1-GSI)/FAR. After defining the scope and limitation of the research, an algorithmic model was prepared to simulate all the parts of the generative design system. The model is based on visual scripting that may be represented in long definitions and several components. This made the manipulation and control of all the processes difficult and time-consuming (Figure 7).

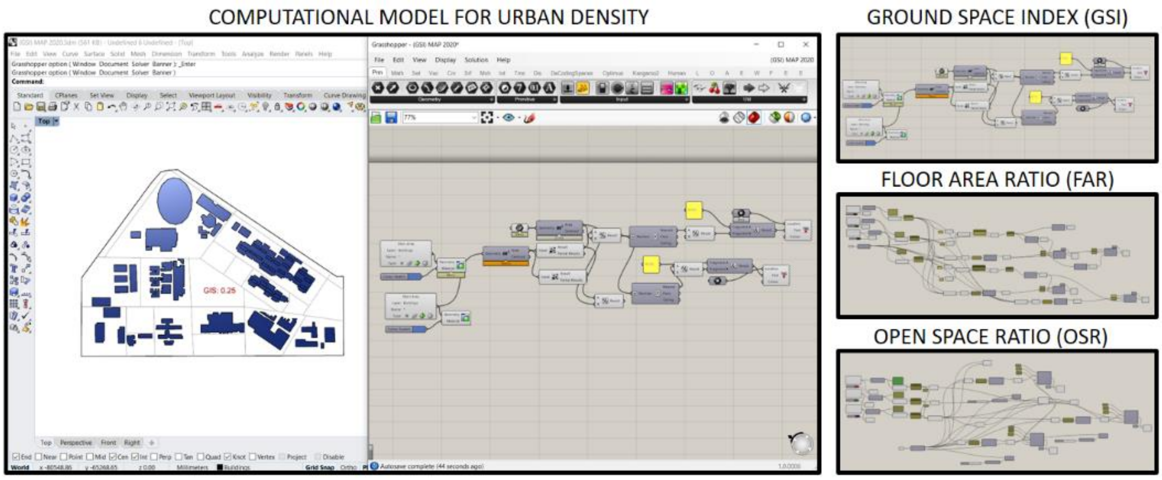

Figure 7. Urban density analysis computational model / Components and main definitions. (Source: by the author)

Therefore, many of those components are grouped under clusters with names to facilitate intervention (size, heights, and depth). The algorithmic model is a significant structure that went through many iterations to define the interconnection between the three system parts (functional connectivity, responsive density, and design pattern) by engaging several components and combining transmission between them. A large number of input parameters have to be redefined and engaged within the process to conduct more flexible actions. This makes the definition of the system inside Grasshopper canvas more complex and lets the designer intuitively face difficulties in managing components interaction.
The main indicators measured with this computational analysis showed a significant level of effectiveness in spatial analysis and simulation requiring just buildings' footprints as input data. It is a visual examination of the space density based on the buildings' footprint data applied with parametric design tools (GH codes). Engage both open space and building blocks, as well as computational techniques, to decode the university campus master plan's characteristics into indicators. First by formulating a computational data set for each building plan footprint recognizing both the volume and the environment open space. It is also shown that the density analysis gives more accurate outcomes than the spatial analysis methods concerning open space proportion and spatial layout structure classifications (Figure 8.).

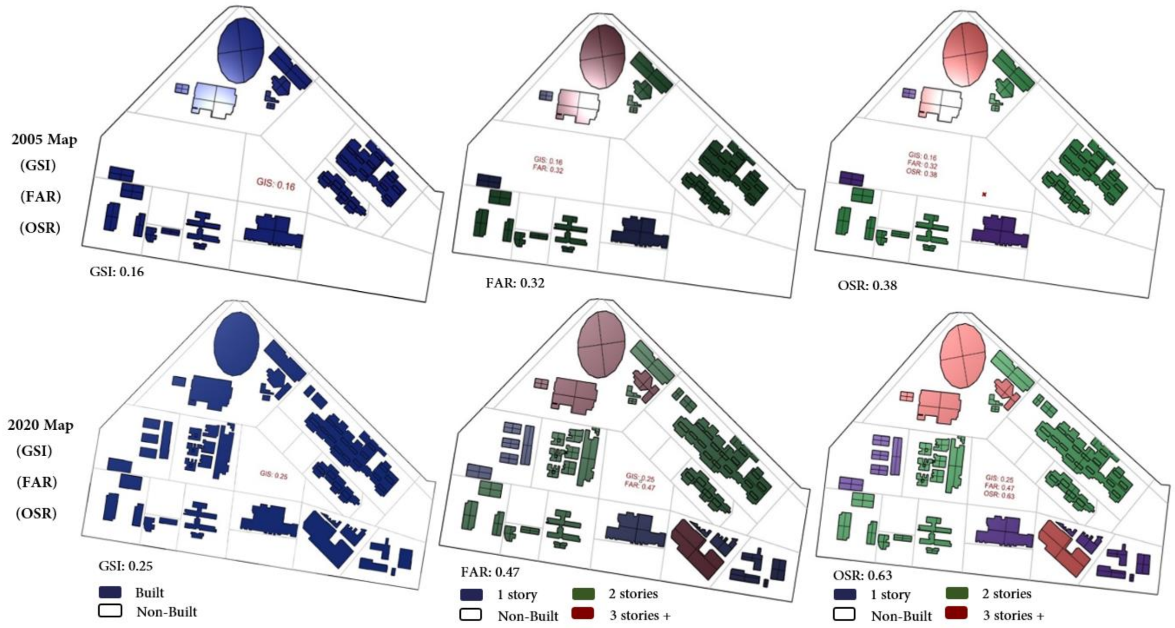

Figure 8. Indicators of the morphological properties at the campus master plan (2005/2020 maps). (Source: by the author)

A research stated that attractiveness could be discovered in different forms such as closeness, relationship, usage, and importance according to the design aim [25]. The analysis in this study only focused on the interaction between open space and built areas. Other social and cultural aspects are not involved in the research because they depend on the users' personal feelings and desires that do not enhance the objectivity of the computational parameters. The attractiveness potential for the ESTU campus is calculated to embrace the street networking, open space, build environment, and the buildings' interconnections. The calculation considered the distance between the various campus facilities, the distance to the main entrance, and the user experiences resultant attractiveness of a grid point.

4.2.2. Visibility Analysis

Isovist describes the part of space that can be seen from a certain viewpoint and calculates the visibility of objects [12]. The properties of Isovist are the correlation with subjective spatial experience. The Isovist region works with mapping the changes of visual properties along a specific path where the Isovist field is mapping properties on a scalar field. By displaying the number of arrays in contact with each face of the extruded volume, it is also conceivable to compute the building visibility and gather numerical data. Many components and functions used represent distinct types of Isovist calculations such as, Isovist field, Isovist region, properties and object visibility (Figure 9.). The engaged parameters are defined as follows:

- Attractiveness: index evaluates the amount of view expansion from the viewer's initial position and is related to the spatial experience of "expansion and context."
- Extent of observation: This index indicates the length between the viewer's point and the axis of the Isovist range composition, which demonstrates the degree of visual attraction and visual direction in the area where the viewer is considered to be.
- Line of orientation: This index evaluates the longest potential visibility and is related to environmental experience.
- Arrangement: The dimension of all covered boundaries is equal to this index. The restricted or bypassed edges are those whose values in the spatial perception are undefined or indeterminate. This index is related to the impressive spatial experience.

According to the stated design pattern and environmental parameters, the outcomes present a variety of possibilities from various locations. Numerous parametric Grasshopper analysis components just use assessment experience. An efficient interconnection of the algorithmic model enabled fast generation and instant results interpretation in any stage of the generation so that the impact of each specific data input could be tested and compared for a 2D scale. The Grasshopper definition is applicable for all experiment trials according to their input parameters and data manipulation. The algorithmic model is initially developed by extracting data from the main gird and involving them in the subsequent components such as lines and polygons that represent visibility values (Figure 9.).

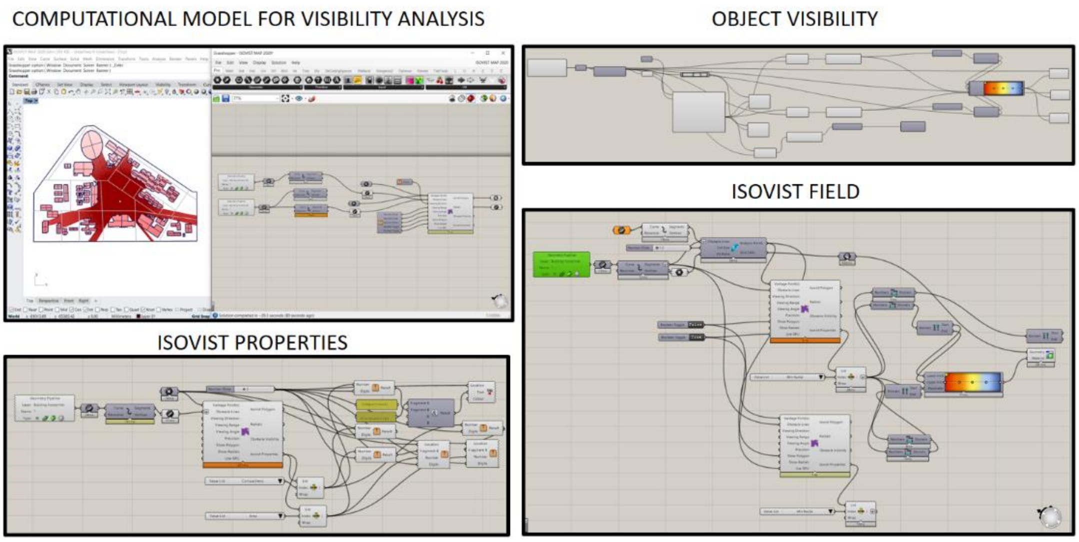

Figure 9. Visibility analysis of computational model / Components and main definitions. (Source: by the author)

According to the Isovist analysis, the high visibility is shown more at the intersection of the streets which could be taken as a context requirement for generative design system application. There are also significant trends of open space existence from the southwest to the northeast, which are illustrated in orange and blue colors. The coherence presented in the distribution of volumes within the area, some of them are better integrated and have high visual representation values, while others show the opposite features. Both plan analysis results lead to an assumption that integration and openness central environment of open spaces are unclear concerning design.

Some areas on the university campus give the chance to visually connect all the parts of the plan while moving through the center. The main street in the center of the campus coming from the northeast main entrance is more dynamic than the others, and this provides both diagonal and horizontal connections between all the regions inside the campus. The open space between buildings is visibly presented in the design of most buildings. The Isovist shows that these types of design patterns are strongly clear enclosed. Also in terms of measure, the buildings with interior open space present a contrasting character to the rest of the environment (Figure 10.).

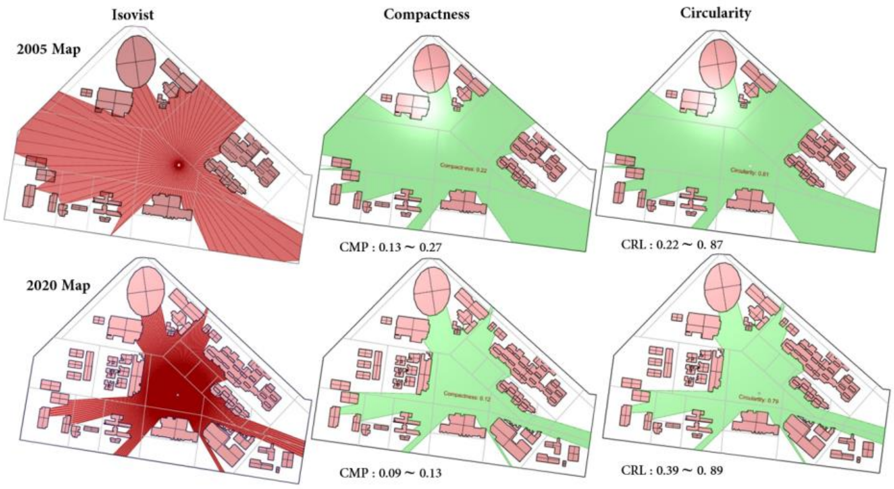

Figure 10. Visibility analysis results - CMP/CRL (2005/2020 Maps). (Source: by the author)

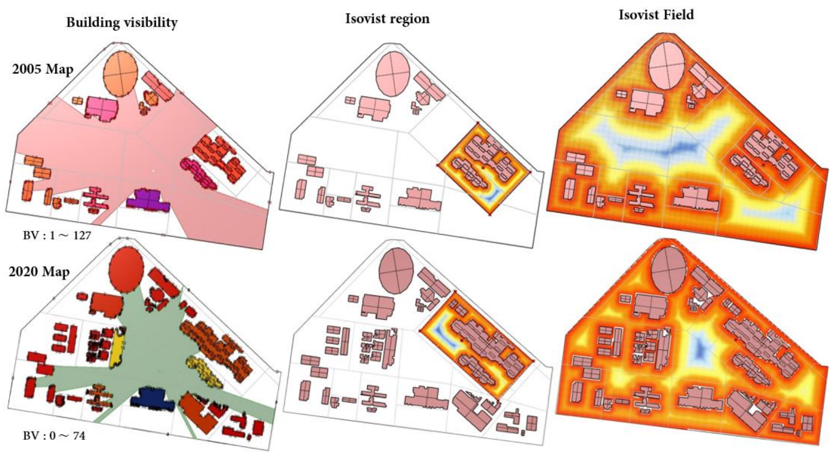

Figure 11. Visibility Analysis Results Isovist (2005/2020 Maps). (Source: by the author)

The colored space in between the buildings represents a relatively compactness and circularity even if the results of the Isovist area seem to be nominal. This is the case in different open spaces which connect the area and play the role of a central environment. The blue color symbolizes exceptionally high space openness as seen from a given location, whereas the orange color represents relatively low space openness as experienced from a specific point. The point of reference is chosen to be on the center of the maps where all street networks intersect. The visibility analysis shows the value of centrality within a specific area. Some point of the environment has a small Isovist area but has relatively a high visual integration value because of density variance. These types of spaces are more considerable when it comes to inside integration, however, they feel very disconnected from the whole environment. Some other parts remain discrete to be detected by the analysis tool.

5. RESULTS DISCUSSION

Studying the development of Eskisehir technical university's master plan over time allowed us to explore the various mechanisms that affected its formulation. Many authors believe that the campus should be diverse, compact, strongly integrated, well-structured, sustainable and urbanized [26]. The 2005 map demonstrates a significantly decreased degree of compactness compared to the subsequent map, significant areas are still being preserved given the major development of the campus, which has undergone a noticeable reconstruction in recent years. While on the 2020 plan, a compromise between conception and realization is becoming considerably more influential, and campus improvement and expansion are at the center stage. It was a challenge to maintain the layout characteristics of the previous maps, while simultaneously developing new approaches to connect with multiple growing conditions throughout the university campus. To underline the aspects for evaluating the composition of the campus in this qualitative research, the results show that the main problems identified for university campuses are; layout and spatial arrangement, connectivity and accessibility, built area and open space (Table 1.).

The use of different design patterns without clear respect to the proportion of open space in a combination of built and non-built areas in the university campus highlighted difficulties in analyzing the environment by observation and visual analysis. As a result, utilizing computational techniques to evaluate the same master plan maps might be more effective. University campus buildings with their simple design pattern are distinguished from early buildings' characteristics. Also, it can be noticed that some of the buildings that were designed later have different architecture. The outcomes from this analysis highlight the development behavior of the university campus master plan give much more about the urban fabric morphology. This allows seeing that spatial development is differing from structured axial morphologies of the street network to a non-structured street network where the buildings and blocks are not regularly located alongside parcels division. The decision of the most attractive point for the design system differs from one area to another and it is linked to the user experience. In this study, the weight adjustment was permitted to be modified based on the unique requirements and characteristics. A more accurate analysis could be done to specify the exact attractive locations of each user of the university campus. Many other attributes such as social and cultural characteristics may be involved in future research.

Table 1. Numerical data of the university campus master plan from spatial analysis (2005/2020 Maps)

	Old Map 2005 (m²) / (R%)	**Existing map 2020 (m²) / (R%)**
Campus Total Area	11403447 m2	11403447 m2
Administrative Units	0.91%	≈ 2.1%
Social Units + Outdoor	80.32%	≈ 62%
Technical Units	0.87%	≈ 1.9%
Academic Units	17.9%	≈ 34%
Total distance/circumference	/	9.46 km = 9.460 m
Total parking area	/	49,044.00 m2

Engaging new computational methods within the design process can provide support for some of its steps, by generating several possibilities that search beyond predetermined design concepts or by changing some phases in unpredicted procedures. It seems that computationally generated design possibilities will be further responding to the user needs and integrated by the designer into a coherent whole under relation software-designer. Computational analysis technique, in which algorithmic model is employed, provides availability of highly specific and dynamic results open to precision and interpretation. This presents an important dominance for spatial and architectural design development. It is used effectively on the master plan scale to test various designs and their performance, but many challenges are presented while applying it on the real scale due to data calculation and parameters manipulation. Several difficulties in limiting inputs and more important specifying the time involved in the process. The computational analysis demands qualified practical designers to determine success purposes based on the understanding available at each phase of the creation of a master plan and interpreting the implications of the land use, density, and design choices on those aims into numerical and geometrical data.

The analysis values show that the proportion of open space within the environment is decisive to highlight the integration and openness of the space. The main benefit of this computational analysis is to facilitate the interpretation of the design environments where the marginal visibility is colored with orange and central visibility in red. The following table summarizes the features and related indicator values of the investigated university campus master plan, such as GSI, FAR, and OSR, among others, that are required for the development of a future design system (Table 2.).

Table 2. Computational design analysis outcomes (Numerical Data) (2005/2020 Maps).

	Old Map 2005 (m^2) / (R%)	**Existing map 2020 (m^2) / (R%)**
Campus Built Area	≈ 67230 m2	454034 m2
Campus Un-built area	≈ 52736 m2	119966 m2
Active campus area	≈ 187196 m2	574000 m2
General open space	≈ 67%	20.90 %
Open space per parcel	40.30%	20.90 %
Open space per building	17% - 20%	17% - 40%
GSI	0.16	0.25
FAR	0.32	0.47
OSR	0.38	0.63
Building Visibility	1□127	0□74
Compactness	0.13□0.27	0.09□0.13
Circularity	0.22□0.87	0.39□0.89

The results show that density and visibility analysis may lead to predicting open space proposals for future design processes. A better analysis still can be engaged by many other computational tools among several practices. However, for this study scope, the visibility and density analysis can allow a generative design system to engage the collected data in the generation process. Besides, the university campus plan that was analyzed is mainly focused on features such as open space, street networks and building block interconnection. It also provides a comprehensive visual representation of the results that could be improved and clarified. It was interesting to comprehend how space functions and how future growth should behave. The visual analysis methods could be used as well to evaluate different other studies and assess the strengths and weaknesses of many design proposals to reach some effective design decisions.

The relationship between a digitalization degree and a regional incorporation degree can be used to assess the method's sophistication. The numerical specifications may be transferred into other computational analysis capabilities via an interactive platform to investigate the relationship between the digitalization degree and the appropriate framework extent of the spatial dimension.

6. CONCLUSION

It is always crucial to make effective decisions on design development when data availability is limited. Nowadays computational studies, which are primarily subjects in the field of architecture and urban planning, have become the focus of the intersection of computer capacities and spatial planning. The search in this kind of situation is based on exploring new techniques and tools that could provide numerical data to help designers and architects to achieve better designs. Consequently, the significance of sophisticated computer programs is getting increasingly crucial in today's architectural fields of study, since several advanced software applications such as Grasshopper are widely acknowledged as generative tools. The measures involved in the research at a basic level compared to capacities that visual programing techniques could perform. All the data collected, including the use of an algorithmic tool to assist the programming methodology of the computational analysis, are regarded as empirical representations that demonstrate the outcomes of integrating design features in the master plan expansion studies. The engaged techniques need to be diverse to search for more performative possibilities with variance in characteristics and design patterns results.

This research is based on contextual and computational analysis of the university campus master plan in two different periods (2005/2020). On one hand, contextual analysis enabled one to pay attention to the specifics and suggestive complexities of how the campus reacted to various circumstances and environmental limitations. On the other hand, visibility and density characteristics of a university campus master plan development showed that these analytical techniques are very responsive to the design limitation and context requirements. Some spatial characteristics are formulated and converted into indicators so may be computed using Grasshopper as a computational tool. This initiates a particularly appropriate data collection for both campus buildings and open spaces. Perhaps in a more complex spatial fabric environment, these techniques have to be improved to process a huge number of numerical data and spatial structures. The analysis techniques used in this section of the research can be enriched and introducing some other data processing methods and morphological assessment approaches that consider open space and built area characteristics. The main intention is to recognize the university campus structure allowing the potential for sustained expansion, carrying the basic framework for the campus' functional development. The campus should be diverse, compact, strongly integrated, well-structured, sustainable, and urbanized. The presentation of the campus area to be as beneficial as possible for our research is provided in the form of maps. Much information is included such as density, zoning, build non-build, and pattern characteristics to describe the university campus typology. Some details such as scale, area limits, and locations are easy to describe, whereas many other attributes like design quality, walkability, and accessibility need different types of data to be calculated.

Correspondingly, this research is a comparative study that explores two spatial design analysis methods which are contextual analysis and computational analysis. It tends to prospect how can computational analysis can assist architects and urban planners in better understanding the development mechanism of specific university campus master plans. In addition to that, this research aims to facilitate the definition of the campus master plan crucial spatial problems that need to be decoded by involving more sophisticated approaches and systems such as computational and generative measurements. To sustainably design or generate an expansion of any university campus master plan, there would be a complete understanding of the development mechanisms and the interconnection logic of its spatial elements. For a public space and as a part of the urban tissue of the university campus, functional connectivity, responsive density and design pattern are the major elements that influence the generation process of the master plan.

Designers remain in control of making the main decisions, and they may determine the appropriate layout from the produced possibilities and post-process the findings to display comprehensive conceptual illustrations. Involving equivalent variables, might be extended to other spatial studies in research consideration. The outcomes of this comparative analysis within this work can be further improved and adapted to other university campus master plan specific situations in terms of design and building arrangement details, mainly of interest for open spaces and different form-shaped buildings. It was claimed that by evaluating Isovist indexes, a novel computational procedure to assess the visual quality of spatial structures could be presented. The findings demonstrated an interaction between the proportion of open space and built area and the Isovist indexes, which might be useful for urban designers and architects during design expansion decision-making. It is almost unexpected to provide any examples of absolute or subjective dominance in terms of visual quality based on the findings achieved, but the presented application has evaluated the visual aspects of each of the university campus maps to deliver a technique to the designers so that they may implement their requested visual characteristics to the future design expansion. Even though the Isovist parameters and the steps that help implementations have effective internal consistency, various outcomes have been reached despite the high potential analyses in the planning process. This procedure might be employed by other researchers as an adequate framework for other comparable investigations if further studies that will be conducted.

CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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USER EXPERIENCE DESIGN AND ARCHITECTURE – AN APPLICATION WITH ARDUINO

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ABSTRACT

User experience design, which provides the emergence of user-oriented designs, while meeting the needs of users functionally, also deals with their emotions and perceptions. With this interactive design approach, personalized design alternatives can be offered in accordance with the expectations of the users. At the same time, the flexibility with changing conditions, demands and pleasures ensures that designs are sustainable. Architecture is one of the disciplines where user experience design can effectively use. The inability of changing of buildings in traditional architecture causes another inability that to respond user's current needs and demands. Thus, in modern architecture many researchers and designers investigate for a solution to create different spaces. Moving, flexible and interactive spaces, which are shaped with demands and needs of the users, give importance to the user experience. In this context, a tent was designed as a temporary shelter with caring the user experience and changes depending on the demands and needs of the user, by using the Arduino Uno microcontroller development board. The prototype experiments of the tent design, which was modeled with SketchUp and rendered with Lumion, were made with the Fritzing program. Arduino Uno, sensors, lamp, relay module and servo motors were used in the tent design and the space was enabled to interact with the user's different senses. Two different sensors, temperature-humidity and sound were used in the study. The temperature-humidity sensor interacts with both the user and the environment. Since precipitation occurs when the relative humidity in the air reaches 100%, the program is coded to turn off the panel on the top of the tent when the humidity in the air reaches 70%. With the help of the sound sensor, predetermined colors are lit on the front panel of the tent with the user's hand clap. In the study, it is aimed to create different experiences by providing the interaction between the body and the space.

Keywords: User experience design, Architecture, Arduino Uno, Temporary shelter

1. INTRODUCTION

User experience design, which emerged in the early 1990s, means encountering the system that has a beginning and an end [1]. Kuniavsky (2003) defined user experience as all the factors that affect the relationship between the user and the user in an organization. In the user experience, the whole relationship between the product and the user is taken into consideration to examine the user's experience [2]. UX (User Experience) can be summarized as the quality of the user's experience when interacting with a product [3]. User experience design consists of five levels: surface, skeleton, structure, scope and strategy [4]. The surface includes visual design elements. Skeleton is information design and orientation design. The structure constitutes the information architecture of the elements contained in the application. Scope is the stage of determining the features and qualities that the design will contain. The strategy, on the other hand, corresponds to the design determined according to the needs and claims of the users [4]. User experience design emerges as a result of the user's current situation (wants, mood, needs, etc.), the characteristics of the designed system (purpose, function, etc.) and the context in which the interaction takes place [5]. This situation allows untold designs and experiences to be experienced in products for which user experience design is important.

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The concept of experience has an important place in the field of architecture, as in many disciplines. Especially with the new developments in information technologies, the concept of experience has gained importance, helping designers to make designs that diversify user perceptions and experiences. Experiencing the space is actualized by interacting with image, texture, smell, taste, and sound. Sensory stimuli, which affect the sensory mechanisms of the space user, are processed, and make the experience possible [6]. While experience is personal, designers can influence users' experiences, but not design. Because experiences vary depending on many parameters such as past experiences, cultural differences, and ages of the users of the space. In order for the design to yield successful results, it is expected to provide solutions that meet the needs of the users during the construction stages of the space. Design cycles are created by determining the needs, identifying the problems, making them aesthetically pleasing by using information technologies, and evaluating the interaction received from the user. This cycle is seen in many areas such as interfaces of applications, architectural and industrial design, and visual channels of communication design. The common purpose of these design approaches is user-oriented solutions that serve the user first and then the society [7]. With the use of user experience designs in the field of architecture, users can actively communicate with the space, making it easier for them to perceive the space mentally and physically. In order to increase the user experience, static spaces can be transformed into interactive, mobile and flexible spaces.

In this study, information technologies were used in order to increase the experience of the users and to enable them to interact with the space, and it was aimed to have a changing and transforming structure of the temporary accommodation area by using the Arduino Uno microcontroller development board. The tent design to be used as a temporary shelter interacts with the user through temperature-humidity and sound sensors and a light source (lamp). The lamp on the tent surface can be arranged in different colors depending on the user's request. In addition, the top cover of the tent is designed as a movable system and it is aimed to come to a closed position by interacting with environmental effects such as rain with the help of temperature-humidity sensor and servo motors.

2. MATERIAL AND METHOD

In this study, information technologies and Arduino Uno microcontroller development board used in order to provide user experience. The tent, which was designed as a temporary shelter, modeled with SketchUp and rendered with Lumion, can be seen in Figure 1.

Figure 1. Tent as a temporary shelter (prepared by the authors)

In this study, which is aimed the user experience, two different sensors planned to be used in temporary shelter design are discussed. The first sensor is the temperature-humidity sensor, and the second sensor is the sound sensor. With the help of the sensors, it is planned that the space will interact with the user and the external stimulus. The temperature and humidity sensor, DHT11, consists of a 1 kΩ resistor. The temperature and humidity sensor uses a thermistor and a capacitive humidity sensor to obtain ambient information. This sensor contains a chip to convert the read analog values into digital signals. Temperature-humidity sensor operating voltage 3.3 V-5.5 V, humidity measuring range 20% to 90%, relative humidity measuring accuracy ± 5% RH, humidity measuring resolution 1% RH, temperature measuring range 0°C - 50 °C (32 °F – 122 °F), temperature measurement accuracy ± 2 °C, temperature measurement resolution 1°C, and signal transmission interval of 20 seconds [8]. Another sensor used in the study is the sound sensor. The sound sensor can detect sound values in different decibels and can control any AC or DC device by using a relay in accordance with the determined value, and it can make them light in different combinations by using LEDs or lamps [9]. In the study, Arduino Uno microcontroller development board developed for Atmega328 microcontroller, which can be seen in Figure 2, was used. The reason for choosing this development board is that the software is open source, and the hardware is affordable. The development board has 14 digital inputs/outputs and 6 analog inputs [10].

Figure 2. Arduino Uno microcontroller development board [10]

In the study, motion sensor and temperature-humidity sensor were connected to the Arduino Uno set, as seen in Figure 3, in order to close the top cover in a rain. The system, which can be seen in Figure 3, was built with the Fritzing program, an open-source startup that enables circuit creation to develop CAD software or run a prototype experiment [11].

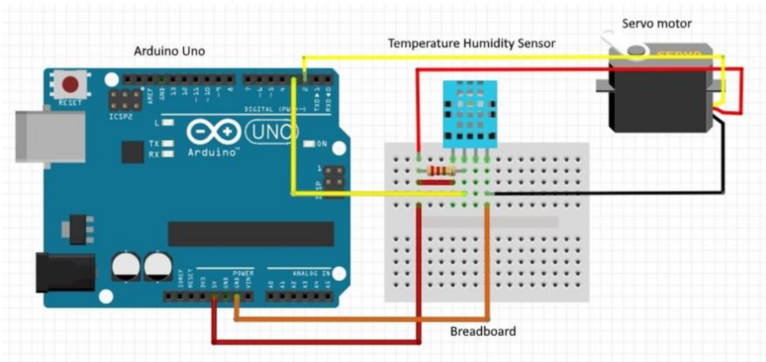

Figure 3. Connecting the circuits of temperature-heat sensor (prepared by the authors)

Thanks to the temperature-humidity sensor in the prototype tent design, the panel on the top of the tent can become closed under suitable conditions, as in Figure 4. Since the water vapor condenses and turns into precipitation as a result of the relative humidity in the air reaching 100%, the top panel has been designed to be closed when the humidity in the air reaches 70%.

Figure 4. Top panels open in sunny weather and closed in rainy weather (prepared by the authors)

Another sensor used to increase the user experience is the sound sensor. With the sound sensor, the user interacts with the tent with the help of a light source (lamp) located on the front of the tent. Depending on the user's request, the lamp on the front panel of the tent turns on when clapping hands or making a sound. Figure 5 shows how the sound sensor is located on the Arduino Uno development board.

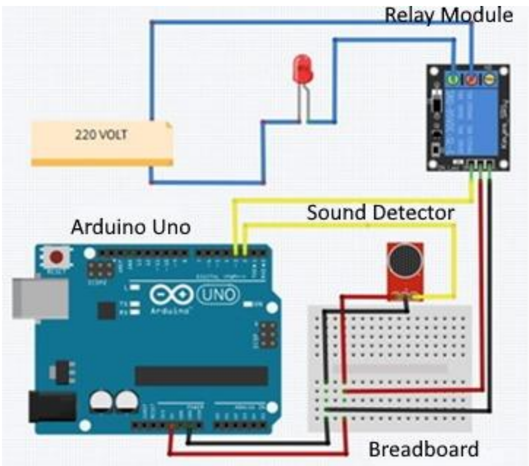

Figure 5. Connecting the circuits of sound sensor (prepared by the authors)

Figure 6 shows the color change on the front panel of the tent design when interacting with sound. Color selection can be changed depending on user request.

Figure 6. Panel color as a result of interaction with the sound (prepared by the author)

3. RESULTS

The mechanization and mass production that emerged after the industrial revolution led to the standardization of the products produced. These products, which are based on the repetition brought by mass production, cannot be continuous because they cannot meet the changing tastes and demands of the users, and this may cause various problems. On the contrary, experimental, creative, and innovative designs emerge with the interactive design [12]. The designs that interact with the user are experience-oriented. The smart phones, computers, tablets, watches, smart clothes, and other interactive products we use can be redesigned in line with the user's requests and tastes.

As a result of the literature review, it has been seen that the products designed by considering the user experience design principles take into account the following principles:

- They are designed to meet the needs of the user.
- They are easy to use.
- Design elements fully reflect the identity of the brand.
- The design appeals to all segments.
- Users feel safe and have no doubts while using the product.

As with the products we use, the user experience also plays an important role in the places we live in. In traditional architecture, the fact that the building does not show flexibility depending on the changing conditions after it is built and does not interact with the users who experience the space has put the designers in search of different spaces. These spaces, which can be mobile, flexible and interactive, can become a smart, sensitive product that can respond to users' requests and save energy.

The spaces using user experience design have the following features:

- They provide spatial diversity.
- They can chang as a result of user requests and requirements.
- They diversify the perceptions and experiences of the users.
- They provide the emergence of flexible, interactive, and kinetic spaces.
- They have the ability to adapt to different seasonal conditions.

In the study, Arduino Uno development board was used to reveal the user experience. When the existing experimental sets are examined, it is seen that Arduino Uno is more affordable than other development boards. In addition, it has been observed that many applications can be made in a short time, as the application set does not require cable connections. In addition, the Arduino Uno application set can be easily transported and stored due to its portable nature.

Sound, temperature-humidity sensors, lamp, relay module and servo motors were used in the study. The user's hand clapping or any other sounds made depending on the user's request enable the lamp used on the surface of the temporary accommodation area to light up in different colors. This helps diversify the user's perception and experience. In addition, with the help of the temperature-humidity sensor and servo motor used in the top, the upper opening of the space can be closed automatically in case of precipitation. This ensures that the tent design shows the feature of a space that is mobile and at the same time gives importance to the user experience.

4. CONCLUSION

The changing social structures and perspectives with the industrial revolution have also caused the housing needs to change. With the developments in information technologies, it has been seen that new space designs that adapt to changing living conditions and transform in line with the demands and needs of the users have emerged. These changing and transforming new space designs can show smart, sensitive and interactive features. The concept of "user experience design", which emerged at the beginning of the 90s, has begun to be considered in the field of architecture as well as in different disciplines. The relationship between the experience concept and the body has influenced designers. Considering that the objects and spaces we use in our daily life are perceived and experienced only by our bodies, the importance of user experience design can be understood clearly. In this context, a tent is designed as a temporary shelter with interactive, kinetic and flexible features that change and transform with the movements of the user and the change of environmental factors. It is expected that this accommodation area will interact with different space and user perceptions with the help of Arduino Uno development board, sensors, lamp, relay module and servo motors. This helps the user to have a multi-sensory experience. It is important for designers to design by diversifying user experience and perceptions, as it is predicted that designs made with emphasis on user experience will take place more and more in our lives day by day.

CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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DIGITAL POSSIBILITIES OF THE ATMOSPHERE: METAVERSE AND HALLUCINATORY IMAGE

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ABSTRACT

Considering the propositions of the virtual universe with its short history, there are digital twins and various economic investments. While the Metaverse points out a novel universe, it is able to promise much more than producing a copy of the self and imitation of conventional economic interactions. To reveal these potentials, it is necessary to determine the areas that must be meticulously focused on. Although Metaverse has permeated daily life dialogues, studies in the academic field are limited. Likewise, research about its architecture and space needs to be developed in this area. No matter how far the new universe propositions go, they still stick with the quantitative values of the physical world. This issue obstructs the creation of its own reality. However, the universe's own digitalized digitalised structure does not require that the imagination of the spaces stuck with a quantitative basis. To avoid quantitative and reductive attitudes, focusing on the atmosphere of this universe may be a solution. The study aims to collide the possibilities of the Metaverse and the architectural atmosphere discussions to make an alternative reading of the Metaverse. Developing theories about the atmosphere of spaces and conducting atmospheric studies about Metaverse allow us to develop meta-experiences of the Metaverse. Focusing on the architectural atmosphere, immediate appreciation, ecstatic being and hallucinatory image will deepen the definition of Metaverse and provide a multi-layered experience. The image of the atmosphere and ecstatic being is associated with a 'hallucinatory image'. The hallucinatory image has a structure that does not narrow down its references to the physical world. With this aspect, it may provide forms of alternative perceptions specific to the Metaverse. The hallucinatory image, parallel with the sensation of an ecstatic being, stimulates us to sense the atmosphere produced by the Metaverse.

Keywords: Metaverse, Architectural atmosphere, Image, Meta-experience, Ecstatic being

1. INTRODUCTION

As an intention of a novel universe, Metaverse provides innovative experiences, relationships and interactions in digitalised environments. So far, developments of such interactions have mostly been followed through media. Although Metaverse has been frequently included in dialogues of daily life, academic studies are limited. Likewise, further research on architecture and space needs to be developed in this area. To envision how the meta-experiences (of meta-universe) might emerge, there is a need to build a theory about the atmospheres of the spaces in this universe. The study aims to superpose the possibilities of Metaverse and the architectural atmosphere discussions and to make an alternative reading of Metaverse.

2. METAVERSE: THE SEARCH FOR META-EXPERIENCES

2.1. The Developments in the Virtual World

Beyond the conventional universe perception, the prefix "meta" (meaning "beyond") and the suffix "verse" (shorthand for "universe"), Metaverse is an attempt to build a universe with other possibilities. To understand the process, we will look at the brief history of the virtual world. According to Dionisio, III and

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Gilbert [1], virtual world developments have basically five phases (Figure 1). The first phase, beginning in the late 1970s, was text-based virtual worlds such as the role-playing dice game Dungeons and Dragons. The second phase, in the 1980s, was Habitat for the Commodore 64 by Lucasfilm. It was a profile commercial application of virtual world technology and the first virtual world with a graphical interface. Habitat employs the term "avatar", as a description of digital inhabitants, in the virtual area. In the third phase (in the 1990s), Web World offered an isometric world. It offers open-ended building capability, incorporation of user-based content and virtual settings for online environments used in real-time. Following that, Worlds, Inc., Activeworlds and OnLive! Traveler enabled users to socialise in 3D spaces. They provided a space based on Neil Stephenson's 1992 novel Snow Crash.

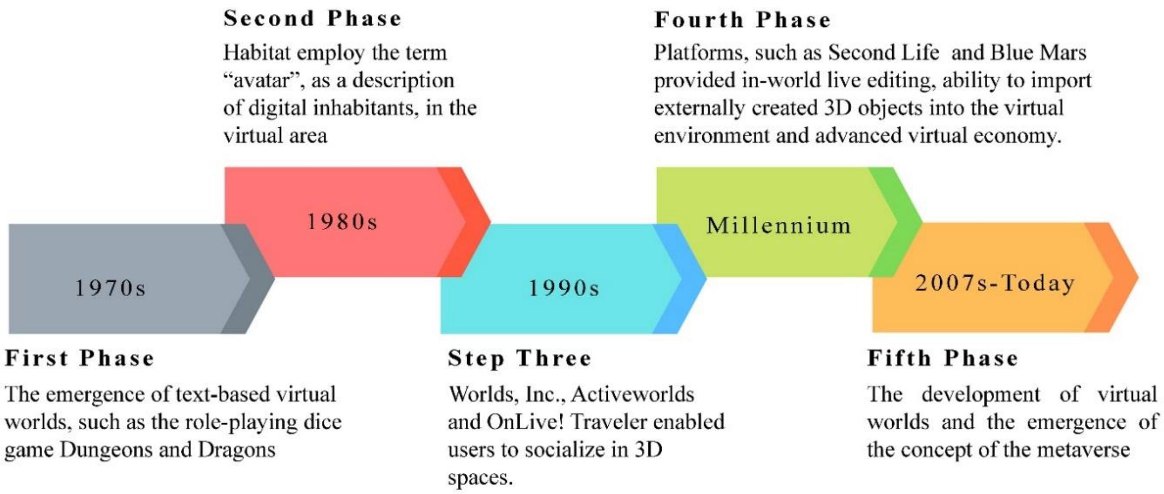

Figure 1. Developments of virtual worlds in five phases (by the authors)

The fourth phase, in the early 2000s, was commercial virtual worlds. These developments trigger involvement of major institutions from the physical world and improvements in graphical fidelity. Platforms, such as Second Life (2003–present) and Blue Mars (2009–present), provided in-world live editing, the ability to import externally created 3D objects into the virtual environment and an advanced virtual economy. The former was virtual world for corporate and educational institutions, while the latter focused on the gaming industry. The fifth phase (2007- present) was open-source decentralised contributions to the development of 3D virtual worlds. Solipsis (2007) was the first open-source decentralised virtual world system. It theoretically allowed new server and client variants to be created from the original code base. Imprudence/Kokua (2008) and OpenSimulator (2009) followed it. The multiplicity of interoperable viewers and servers, similar to the Worldwide Web, was last parts of the fifth phase. Users can choose among virtual words without compatibility concerns along with standard virtual world protocols, formats, and digital credentials. In line with these developments, Metaverse introduces the environment's level of spatial, environmental, and multisensory realism that creates a sense of psychological presence. The concept of Metaverse, with its widespread use in the 2010s, has been integrated into everyday life. It has become to have a significant role in many fields such as education, trade, travel and shopping. With VR and AR technologies, reality has begun to be perceived in a novel way.

The change in communication paradigms emerged from computers in the 1990s, the web in the 2000s, and mobile devices in the 2010s. Today, the paradigm shift may happen with Metaverse by adding a new dimension to the digitalisation process. In cyberspace, the aim is to produce all-inclusive experiences [2].

In his statements on Metaverse, Zuckerberg [3] declared that the sense of presence and togetherness will be established in shopping, leisure, and educational activities. This process shows that experiences beyond what we can imagine may also occur with such technological advances. It is evident that a new meaning of the world and medium for social issues will emerge as a result of meta-experiences. Along with this belief, there were many investments as follows: Facebook's change of name to 'Meta' and its acquisition of Codec Avatar, a virtual reality initiative, and ByteDance's acquisition of Pico Interactive and so forth.

2.2. Various Approaches to the Metaverse

As a first reaction to such developments, sceptical approaches stem from stakeholders of technological investments focusing on just economic benefits. Also, the extreme speed of developments bring about struggles for adaptation. Likewise, discussions about the truth have similar tensions and extend to the design process [4]. With technological tools (e.g., AR and VR devices), post-truth arguments have become remarkable again. Accessing resources in a short while may engender a tendency to democratise against the restrictions to obtaining information. However, the researchers predict that the technological superiority of developing countries will increase, and the cultural divide will become sharper [5]. In terms of hardware, which is often included in the components of the Metaverse, it is also challenging to obtain the powerful computers and connections for such a universe [6]. The investments of various companies have been mentioned before as interest in this field. Nevertheless, the potential domination of these companies may result in a problematic turn. Tinworth [7], with a concern caused by this possibility, emphasises that companies should not be allowed to have hegemony.

2.3. Metaverse and Self

Reflecting one's own self and body as she/he perceives it constitutes the process of corporeal being in the physical world. There is the creation and reflection of more than a self in the media. Hence, different profiles represent different selves. Although represented selves are similar at some point, there may be challenges for an interactive network among them. Based on the precedents in social networks, a universe with replicas of bodies from the physical world cannot generate experiences beyond the familiar ones. Considering the Metaverse as merely the presence of a twin self corresponds to a reductionist attitude as a replica of the existing world. On the other hand, the presupposition of a different 'me' may facilitate grasping the unique possibilities resulting from Metaverse. That 'me' will probably turn into a single and intricate self-related to the body.

2.4. Initial Steps for Metaverse

The motivation for developing a new universe inevitably lies in economic benefits. Advancements such as NFT (non-fungible token) produce new economic models beyond conventional lines. Such models are essential initiatives in confirming the uniqueness of the values that will occur in the Metaverse. However, it is still in earlier phases, and the imagination of meta-experience (beyond the existing experiences) is limited. Here, the economic flows have not found their original aspects yet. With Metaverse as an economic initiative, there is a fiction offering a twin life beyond the internet (but mostly imitating the physical conditions) in the virtual world.

Along with the possibilities of the Metaverse, users tend to pay attention to their representation and spend money on it. Following that, brands develop various attempts to take their place in the digital market. Bitmoji (first in 2016) has collaborated with Bergdorf Goodman to offer luxury clothes for their users' avatars. In 2018 Carlings launched its first digital clothing collection called Neo-Ex. Until the Metaverse, digital clothing remained just 2D photographs and videos. Users have an experience as though they are wearing these outfits through Metaverse. The emergence of such perception has accelerated highly-known brands' presence in Metaverse. In 2019, 'The Fabricant' was presented as the world's first digital fashion studio. It is a studio where users can also become digital fashion creators. The world's first piece of digital couture created by The Fabricant and worn by Johanna Jaskowska sold for $9,500 (Figure 2).

Figure 2. A digital dress by The Fabricant [8]

The Animator Overcoat, designed from liquid metal in collaboration with The Fabricant and Toni Maticevski, presents users with possibilities that do not exist in the physical world. It is reshaped by adapting to the new world identities of the users (Figure 3).

Figure 3. The Animator Overcoat [9]

In 2021, Gucci joined this trend and sold the digital design shoe, which appears on the screen with the mobile phone when the camera pointed towards the feet, for $12.99 (Figure 4). Gucci also began to create virtual spaces, called Garden, with special requirements to sell their products in a Metaverse. Moreover, Gucci collaborated with Roblox company, presented a virtual bag for sale, and sold it for a higher price than in the physical world [10].

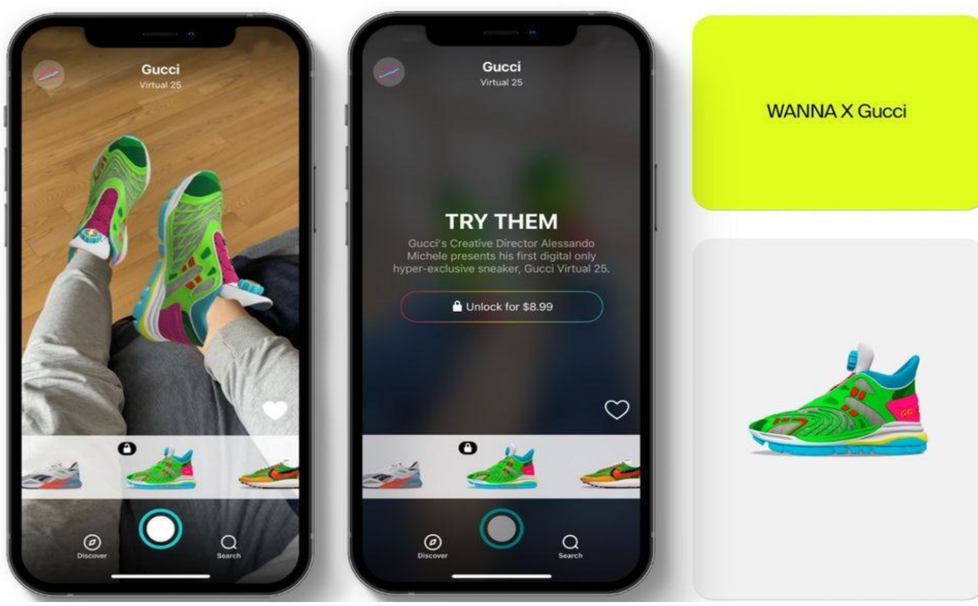

Figure 4. Digital shoes by Gucci [11]

The virtual world of the metaverse is leading to the development of business environments that are much more complex and multi-faceted than existing models. Intertwined physical, electronic and virtual spaces have economic, social and political consequences. Companies need to find novel and systematic ways to take place in virtual world of Metaverse [12]. Dan [13] demonstrates the interest of brands (e.g., Coca-Cola, Nike, Microsoft) in NFT technology with personalised products. Such collaborations, investments and expenditures indicate that the interest in the field is increasing. However, the digital media experiences are based on social status indicators (such as clothes and bags to present social class). It shows that novel experiences have not started to expand and have yet reached their potential to generate and transform the imagination. Similarly, initiatives such as digital marketplaces and art galleries result in conventional relationships based on not fully exploring the possibilities of digitalisation.

2.5. Introduction to the Possibilities of the Metaverse

Personalized tokens like NFT are one of the ways to create a unique experience environment. Further, expeditions between spaces and reformation of the time as milliseconds liberate users and spaces. Adaptable scales of spaces depending on users also expands the range of personalised experiences.

Metaverse offers both production and cooperation in many fields such as economy, art, education and culture. However, its digital-based structure engenders some security concerns. The pace of technological developments beyond expectations, profit-based contents; and the lack of control and legal regulations causes threats and problems. Studies conducted in China point out the concern that this system may establish dominance over others [14]. There are also no strict legal regulations in this area throughout the European countries.

Considering all the possibilities and concerns, the Metaverse has the potential to transcend conventional economic and spatial relations. However, there is a need for studies on how to construct the meta-experiences of the meta-universe. Although it is not a trend in current dialogues, theories about the atmosphere of spaces and atmospheric studies will allow us to define these meta-experiences.

3. ARCHITECTURAL ATMOSPHERE AND DIGITAL POSSIBILITIES

3.1. Basics of Atmosphere

In the literature on the atmosphere, Heidegger [15] has a starting point and stresses the concept of mood and attunement. They originate as Stimmung (mood) and Einstimmung (attunement). There are different translations of Stimmung, such as 'mood' or 'Being-attuned' [15]; 'attunement' [16]; disposition' or 'affect' [17]; 'an attunement to things' [18]. "It seems as though a mood is in each case already there, so to speak, like an atmosphere in which we first immerse ourselves in each case and which then attunes us through and through" [19]. Having some moods characterise the being. Further, the mood is influenced by how things stand out from themselves in both material and mental senses [20]. A space envelops us in a particular atmosphere or mood. The atmosphere is a phenomenon that transcends boundaries like subject and object. Its integrative attitude ties individuals, places and things in the space.

Atmospheres spread uncontrollably over the space rather than oriented toward an object or subject. Once entering a room, a specific atmosphere begins to be sensed; it is quite difficult to determine where the atmosphere is. Since the non-directional structure of the atmospheric orientation, "we are unsure where they are. They seem to fill the space with a certain tone of feeling like a haze" [21]. Due to all these blurry outlines of the atmosphere, there is no place to discuss a crystallised image of it. Although this makes building explicit theories on atmospheres difficult, it also prevents being easily exposed to a reductionist approach. Another characteristic that enhances blurred sight is the immediate appreciation of the atmosphere. The complex integration of numerous factors recognised as an atmosphere, emotion, mood or ambience is comprehended suddenly. Thus, this is an immediate affective reaction that emerges spontaneously. Zumthor [22] explains his atmospheric experience as "*I enter a building, see a room, and - in the fraction of seconds - have this feeling about it*". In other words, atmosphere envelops the subjects who become immersed in them before logical reasoning. Sudden immersion into affectively filled tones of the space is critical for the internalisation of spatial experience.

3.2. Ecstatic Being

In addition to the atmosphere itself, discourses about the entities located in it have been developed as "ecstatic being". Being of a thing is not limited to its physical shape; it may step out from itself [23-24] and imposes itself on other things. Ecstasy of things transcends their own tangible borders and diffuses themselves onto the physical world. The being of an object separates itself with its own ecstatic tone rather than its physical and tangible distinctions. Its ontological reality tinctures and attunes the world in a sense the ecstasy of a thing in concert with other things.

With the intersection of ecstatic matter and people's state of mind, social codes shape the atmosphere. In this respect, the atmosphere is constituted by the presence of subjects and the ecstasy of things. We should focus on how the totality of ecstasies makes it what it is, rather than grasping what a thing is [25]. Because ecstatic beings correspond to essence beyond the superficial properties of things.

3.3. Hallucinatory Image in Architecture

The image of the atmosphere and ecstatic being may differ from the conventional understanding of the image. Subjects can suddenly find themselves in an atmosphere and quickly adapt to the process of becoming a part of that atmosphere. We claim that 'hallucinatory image', corresponding to the ambiguity and instability of the atmosphere, enables this transition.

With questions about observation techniques, Crary [26] examined how the status of the observer was redefined by the early 19th century. He analysed the stereoscope, a primitive photographic instrument. Stereoscopic image, as he noted, is an assemblage of local zones of three-dimensionality, zones imbued with hallucinatory clarity, and it cannot obtain a homogeneous modality. Therefore, the hallucinatory image had a presence in the early dates of technological tools initiatives. At that time, technological limitations provided the gaps to allow for such images.

Hallucinatory experience also has place in the texts of Merleau-Ponty [27], who examines the relationship of myths to the body. According to him, myth has an essence within the appearance; the mythical phenomenon is not a representation but a genuine presence. Thus, individuals who experience their environment through mythological consciousness are able to go beyond critical thinking that takes place in merely geometric space and prioritises objects. Hallucinations and myths result from shrinkage in space, and they are a rooting of things in our body. Therefore, they are the oneness of man and the world and the kind of proximity of the object. Hallucinations and myths are repressed by everyday perception or by objective thought. However, philosophical consciousness rediscovers them.

From another perspective, there is a hallucinatory effect in an artistic experience, especially a cinematic one [28]. Moving images substitute our thoughts so that we can no longer think what we want to think. In a similar vein, architecture can lead human intentions, emotions and thoughts with the hallucinatory air resulting from the space. Therefore, we claim that the atmosphere may have hallucinatory tones (with hallucinatory air in the diffusion of atmosphere). Figure 5 shows some experiential studies of the hallucinatory image in the air.

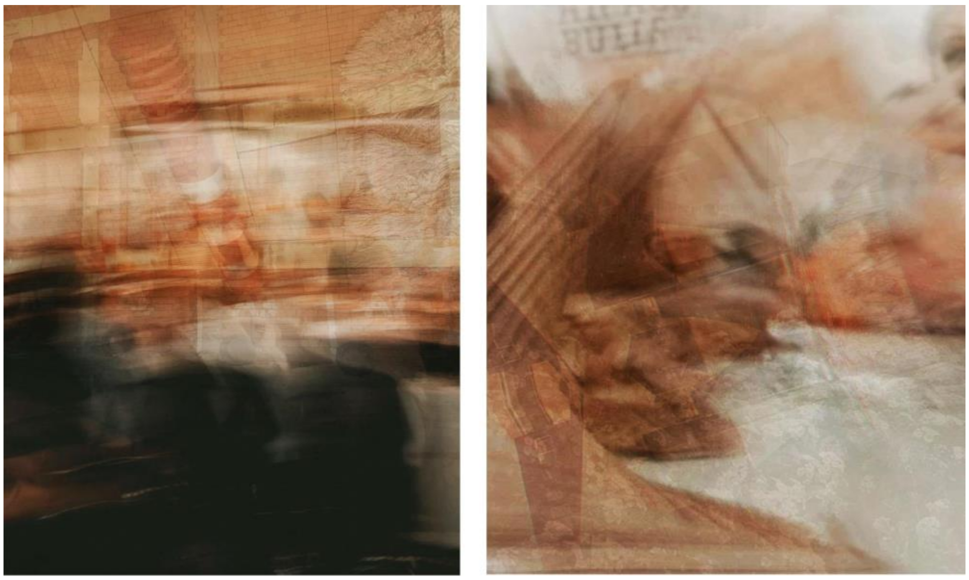

Figure 5. Hallucinatory image experiments (by the authors)

Neither a thing's description nor visual representation completely corresponds to the thing itself. They are developed to communicate by mediating the presence of the thing. In such descriptions and representations, things move away from their ecstasy. By them, the mere appearance is received without the substance and essence. Therefore, ecstatic being is not able to being sensed in representations but in atmospheres. In a nutshell, the ecstasy of things is significant owing to stimulating to emerge and evoke its presence. To step out from itself and imposes itself on other things as an ecstatic being, there is a need for attunement (*Einstimmung*, by Heidegger [15]) in the atmosphere. We suppose that such an atmosphere, especially in discussions of digital space, can be built with hallucinatory images. An alternative reading of the Metaverse has been developed by the collision of possibilities from the Metaverse and concepts of the atmosphere (e.g., ecstatic existence, attunement, hallucinatory image). Our study introduces the meta-experiences of Metaverse (primarily spatial experiences).

4. ATMOSPHERE, ECSTATIC BEING AND HALLUCINATORY IMAGE IN METAVERSE

No matter how far the new universe propositions go, they still stick with the quantitative values of the physical world. It obstructs the Metaverse to create its own reality. Investments from mostly top-brands, high-priced purchase and sale in such universe models provoke quantitative evaluations (in the definitions of Metaverse). Requirements for advanced hardware with their quantitative superiority also prioritise quantitative perception. However, the universe's own digitalised structure does not require that the imagination of the spaces stuck with a quantitative basis.

Considering the virtual spaces of the Metaverse, there is a spatial dimension which is open for further research. Parallel with the elaborations of NFT technologies and the economic structure of this new universe; we need to focus on space in there and explore the potential meta-spaces of Metaverse. Hatıpoğlu and Tokman [29] developed various discourses on atmosphere and its perception in digital space. As a follow-up study, several points can be addressed specific to Metaverse. With the sensation of the presence, Metaverse can find out about its unique experience. Such experiences should have atmospheric aspects as a key to feeling existence beyond those coming from digital platforms (e.g., Zoom). Böhme [24] discussed forms of presence and referred to the ecstatic being for them.

Metaverse is less likely to parallel with the twin identity of the virtual world. The presupposition of different "me" (as an individual of meta-experience) will evolve into a whole and intricate self. Even though more than one individuality due to the different codes of behavior in various social status, they are dissolved into a single body. More than one individuality is currently managed in a single body due to the different codes of behaviour in various social statuses. This shows that the self is not entirely built with a disjunctive and duplicative procedure. The creation of self in its own reality, instead of imitating the realities of other selves, fits in the ground of Metaverse. In hyperreality through simulacra, as Baudrillard [30] noted, people are rendered incapable of thinking with the illusion of reality completely formed in mind, and they make their choices based on unreal things that replace it by making them feel as real. Therefore, the real thing is destined to be a copy of the real. Universes, where the real is reshaped by existence and self, have no chance to hide the truth. Because perceptions have turned into instant realities.

The word 'universe', also at the root of the metaverse, includes an attitude that covers many fields in a single medium. Further investigations are required in all "meta-" components of this medium. For experience and image, the following question arises: "How is an image formed beyond the (conventional) image?". There is a need for discussions and explorations of what are meta-experiences and how they may emerge. Beyond digital representations, we suggest that such image is able to be formed with only atmospheric concerns. We call "hallucinatory image" for these meta-images as a trigger of ecstatic being. Although still an introductory proposition, hallucinatory images can generate the meta-image of the meta-experience in Metaverse. To recognise this experience and image, researchers and developers should allocate a important place for the atmosphere in the Metaverse.

Advanced hardware and super-fast internet connections are requirements for realistic (and real-time) images as a replica of the physical world. These required resources are not available to everyone. Here, we should focus on spatial experience with atmospheric priorities rather than a setup that requires compelling systems with visual priorities. Former priority can increase accessibility, thus, democratising spaces and experiences of Metaverse. In the latter priority, struggles in development are inevitable. Technical data such as pixel density and images should remain a secondary layer. The focus should be on how to design and build the hallucinatory image as the meta-image of this universe. Because creative dissolution from physical reality will not be available by collecting physical images or creating a twin identity and reality. Ecstasy of things and subjects may facilitate to build of hallucinatory images and novel experiences of Metaverse. Attunement of ecstatic beings and hallucinatory images may lead the literature on atmosphere in new directions.

5. CONCLUSION

Along with the promise of a novel and unique universe, Metaverse brings much potential in the research area. Although it seems like a medium where commercial enterprises, for now, it also enables to go far beyond this. The meta-experiences, self, and unique image of this universe will construct themselves in the process. In terms of spaces, there is an area that should not be overlooked at the introductory stage of

Metaverse developments and research: The atmospheres of spaces. The phenomenon of presence in virtual environments should be reviewed along with the presence in atmosphere discussions. The tones of the atmosphere are open to being sensed via ecstatic being. Ecstasy is considered a direct manifestation of the essence. In this respect, the ecstasy of things corresponds to moments when the essence becomes apparent. The image associated with the atmosphere and ecstatic being address as the "hallucinatory image". Such an image gets rid of the destructive effects of digital representation on ecstatic being. Therefore, hallucinatory imagination defines and redefines images formed by immediate appreciation of the nebulous diffusion. Similar to atmospheres, these images have an uncertain structure due to their ambiguity and sudden appearance. This structure intensifies the hallucinatory affect. With the aforementioned phenomena and concepts, this study expands the spatial and digital theories around the discussions of atmosphere.

CONFLICT OF INTEREST

The author(s) stated that there are no conflicts of interest regarding the publication of this article.

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AN INTERDISCIPLINARY EXPLORATION ON CLIMATE NOTION IN DIGITAL DESIGN RESEARCH

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ABSTRACT

Research related to climate concepts has started to be more interdisciplinary with the climate change awareness. Climate action, and climate-positive design research topics are common notions among design disciplines, especially in architecture and landscape architecture. It can be said that computation, digitalization, performance-based simulations of environmental effects, and production methods in digital design are initial topics that come to the forefront concerning methodology. The reflections of these methodologies differ according to the aims and objectives. This paper aims to examine which notions and word phrases are used in the literature on climate in digital design research in a comparative way. Within this scope, The International Journal of Architectural Computing (IJAC) and The Journal of Digital Landscape Architecture (JoDLA) are chosen as academic resources indexed in the Scopus. To obtain the differentiations on climate-related concepts and their associations with other fields in an interdisciplinary manner; published research articles' titles, abstracts and keywords are defined as datasets. The examination is conducted through the data mining method as a deductive approach, using the main words are separated and associated with various phrases, and binary term occurrences. The outcomes are visualized through a map to reveal the relations of the notions that occur in the research. The findings reveal that both disciplines work on environmental issues from the context relationality stage. Although landscape architecture seems to be more related with the environment, climate and ecology trio, the binary-term occurrences show that there is not much difference in the research rates. Nevertheless, considering the close relations with environmental and climate issues in the landscape architecture discipline, the specialization is not high in terms of computational approaches regarding architecture. It is anticipated that this research may be used in future interdisciplinary literature and methodological approaches in digital design research in architecture and landscape architecture.

Keywords: Data mining, Climate, Interdisciplinary research, Digital design, Data visualization

1. INTRODUCTION

The environmental problems that started to increase in the last decade and the awareness in parallel both had a significant impact on design disciplines. Due to the sudden impact of the industrial revolution, urbanization and natural area degradation have started to arise. Current design discourses and methodologies are sourced from these environmental problems and their spatial echoes. The greenhouse effect, urban heat island, and eminent carbon footprint are fundamental grounds for global warming and climate crises [1]. Since 2015, the necessity of keeping global warming at 1.5 degrees has started to be mentioned with the significant risks that 2.0 will bring [2]. Reducing carbon emissions, which is the most crucial regulator to lower the greenhouse effect and rebinding the carbon in the atmosphere to the soil have constantly been on the agenda with the Paris agreement [2] and Cop26 [3]. Therefore, the importance of numerical methods has increased for the performative evaluation of ecological and environmental characteristics. In this regard, both indoor and outdoor sustainability studies such as surface water collection [4], enhancing micro-climate [5,6], or energy-intensive facade designs [7] were produced with simulations and analyses offered by digital technologies. In addition, social interactions and their impact on the environment opened up novel gates in spatial studies. Therefore, the spatial projections that emerge from reciprocal relations which are handled with a performative approach has pushed the designers to seek new computational methods and methodologies [8,9]. These methodologies

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vary in architecture and landscape architecture regarding the design problem and process. The foundations of the design problems are set upon space and environment, and many notions may diversify in terms of use and definition like time, movement, scale, material, etc. Therefore, design, simulation and production mediums, process, methods, and methodologies also differ accordingly.

Non resemblances can be spotted if the reciprocity of the digital and computational design methodologies, consisting of rules and procedures, are examined in design disciplines. In connection with each discipline's theoretical background, design procedures and contextualizing in digital approaches vary. Therefore, it can be deduced that the model inputs required in architectural design do not have the exact equivalent in landscape design and even fall short. The engagement of computational methodologies within the landscape design process is ongoing. While this engagement deals with various aspects in the focus of architectural design, it is also crucial to reveal its adaptation in landscape design. To ascertain the common grounds of climate notion among these disciplines, it is crucial to unfold the relations, distinctions, and collectives regarding computational backgrounds.

1.1. Computation in Design Disciplines

The innovations and developments ensued with each other pertinent to the convergence of design and computability. Particularly, with the definition of design problems in the form of graphical expressions, which began in the mid-1970s. While the emergence of object-oriented design methods in the early 1980s, the tools offered by new technologies began to evolve. Especially from the 1990s, architects tended to adapt design methods and tools to innovative visions regarding cognitive development in computation and digital design. With the origination of the first "digitally intelligent designers" [10] generation, digital design and computational methods mainly were associated with variations and non-standard forms. In conjunction with global networking systems, the idea of mass customization that stemmed from the industrialization era has been shifted to the mass collaboration known as the second digital turn [10]. With this regard, the cumulative literature of computational design theories, methods and tools reflected in design practice has become more prominent, especially in architectural discourse. This context is assumed to be informed by parametric design, topology and performance concepts and forms the basis of digital design practice [11].

Nevertheless, the fundamental changes have reshaped the architectural design mindset; similarly, landscape design has been also in a state of flux. Considering the environmental notions and the tenets that it beholds; new approaches and methods carry significant importance as in computational design development. Regarding the stages of development and impacts on the computational approaches, digitalization effects and technologically informed design methods occur in different ways. Ervin [12] proposes three modes to explain this engagement in phases: new tools, new languages, and a new design environment. The initial mode uses the software as a tool while highlighting its importance in the design process by giving an operational function. Another is creating a new language that aims to improve the design by customization via writing codes or software. Finally, he argues that the interconnectedness of all the digital devices used today creates a new environment to produce computational "interactive" and "responsive" landscape design, developed through the concept of the "Internet of Things (IoT)". It can also be argued that knowledge-based interpretation and form-finding methods create a common literature and lexicon with digital design discourse by bringing together interdisciplinary and cross-disciplinary approaches, as in scale and theoretical background. Therefore, architectural design, like urban design and landscape design, can be seen to coincide with similar approaches by using common tools and interfaces, but also to differ from each other in terms of scale and purpose.

That is to say, digitalization has created a ripple effect that forces production and design approaches to evolve and change. In particular, design practices put the way of production and the roles of designers up for discussion. Therefore, it is crucial to examine both the constraining aspects and the facilitating effects of digital tools. The engagement of digital tools and computational methods in the design has evolved from drawing planes into coding interfaces. This development process created interchangeable characteristics for designers, from "draughtsman" identity to "scripting" capability [13]. However, reflections of these changes in designer identities varied regarding discipline purposes, congruity of digital tools, and scope. From this point of view, alignment with cross-disciplinary assessments on computational approaches and notions provides critical sight to the coherence of current digital design trajectories and overcoming the limitations of potentials.

2. METHODOLOGY

This paper aims to examine the design discourse trajectories concerning climate awareness in digital design regarding architecture and landscape architecture. Co-word analysis and data mining methods revealed the differences and gaps in related literature concerning climate crisis, climate action, and climate-positive terms. Two academic journals, the International Journal of Architectural Computing (IJAC) and the Journal of Digital Landscape Architecture (JoDLA) journals, are selected as the primary sources. Issues published in these journals were evaluated regarding concurrency, starting from 2016, the origin of JoDLA publishing, to 2021. 2016 is also the year that the Paris Agreement entered into force to reduce countries' emissions and adapt to the impacts of climate change.

The methodologies and approaches for climate responsiveness and the environmental sentience of design disciplines are the focus throughout the cross-disciplinary evaluation. Regarding this, the method of the research was structured in six stages: (1) gathering the metadata of research from the indexed database, (2) preparation of the data, including selection and assessment of data pertinent to the title, keywords, and abstracts, (3) context relationality with the environment, ecology and climate keywords using all metadata, (4) data sorting based on binary term occurrences to create relevant sub-groups, (4) goal and method sentence extraction, (5) data mining by creating word associations in RapidMiner processor and mapping (Figure 1) the extracted results as patterns with GraphCommons [14]. The evaluation of resemblances and incongruities followed the relational mapping of the data obtained from both sources. During the metadata collection phase, the data of both journals were obtained from the Scopus database by excluding the studies with missing data or inaccessibility. With this approach, an evaluation pool was created throughout Title- Abstract-Keyword (TAK) and Goal and Method Sentence (GMS) clusters.

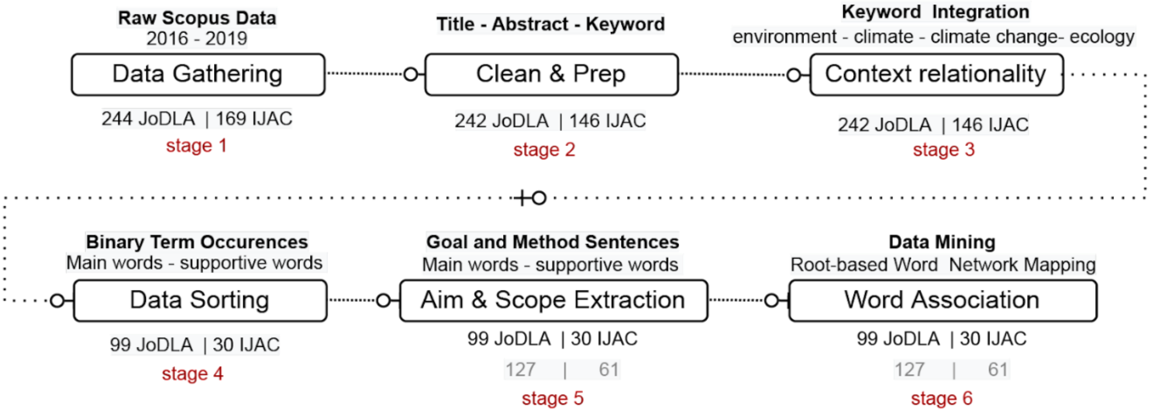

Figure 1. The main steps of the research (Source: authors)

3. MAPPING THE TRAJECTORIES

With the revolutionary creation of Sketchpad by Ivan Sutherland in the 60s, architecture became more interested in integrating the digital and computational fields into its design process. The initial interest was in tool innovation and adaptation. Afterwards, the researchers sought the potential of these in terms of mediums. Various research has expanded the deeper relations of computability in architecture, such as theoretical backgrounds [15]. Some directed the academic research orientations toward design research [16,17,10]. Besides research on theory and practice, design education research gained importance in integrating computation and digital mediums into architecture and design education. In parallel with the connection of computational design with architecture, the Computer Aided Architectural Design (CAAD) conference series has played a vital role in broadening and deepening this new field of research [18,19,20]. These conferences have regional focuses such as the Association for CAD in Architecture in North America (ACADIA), Computer Aided Architectural Design in Europe (eCAADe), The Association for CAAD Research in Asia (CAADRIA), The Ibero-American Society of Digital Graphics (SIGraDi) and The Arab Society for CAAD (ASCAAD). On the other hand, there has been only one conference named Digital Landscape Architecture (DLA) focusing on computational design in landscape architecture since 1999. In particular, studies examining the research focus of the articles published in CAAD conferences individually [21] or across them [22] have taken an ontological approach. Seni and Hodges explain ontology as a formal conceptualization of "what exists" within the domain of science [23].

3.1. Data Gathering, Cleaning and Preparation

In information science, ontology is related to a technique that enables knowledge sharing and reuse [24]. Thus, ontological approaches coincide with data mining techniques related to bibliographic studies. In this context, there are common interests like automated classification [25] and contextual relations [26]. In this paper, ontological literature reviews of architecture and landscape architecture disciplines were conducted regarding digital and computational design domains. To this end, the bibliography was searched by going back to the publishing origin of the Journal of Digital Landscape Architecture (JoDLA). The concurrence of the International Journal of Architectural Computing (IJAC) and Journal of Digital Landscape Architecture (JoDLA) was elaborated in a time interval between 2016-2021, as aforementioned. Both journals adopt peer-reviewed and discipline-specific computational approaches. IJAC is dedicated to broadening the foundations of computer-aided architectural design, which was found by eCAADe, ACADIA, SIGraDI, CAADRIA, and CAADFutures (Acadia). On the other hand, JoDLA has a theoretical and practical focus on landscape architecture lenses, primarily in the annual international Digital Landscape Architecture conference (Gis. point). The recent articles of the specified time interval of these journals constituted the metadata of the research. Accordingly, by eliminating the null data, 146 out of 169 articles for IJAC and 242 out of 244 articles for JoDLA were obtained from the Scopus database.

3.2. Context Relationality

In this step, before moving on to the detailed word-based associative analysis, the basic relationship of both journals with the context of the research was questioned. For this purpose; all titles, keywords and abstracts were organized. In order to further infer on climate change and climate-responsive design tendencies of both disciplines, fundamental keywords were structured into two groups, main words and supportive words list. Considering the relation of climate change research between environmental science (Scopus, 2021) and its ecological solutions; ecology, environment, and climate were determined as the most related keywords with supportive words listed; awareness, change, sustainability, responsive, micro, and efficiency. Firstly, to eliminate the unrelated data and out-of-context issues, context relationality was checked by using only the main words and climate change terms. Primarily, the general contextual relations were elaborated into keywords such as "ecology (eco.)", "environment (env.)", "climate(cl.)", and "climate and change (CC.)" (Table 1). The word "environment" has been the subject of significant research in both journals. %31.5 of the research in the IJAC journal and %36.3 in the JoDLA journal contain this word. However, at this point, it should be considered that the word "environment" can also describe design environments or interactive spaces in the field of computational design. Therefore, the word "environment" in research should be evaluated in its context. While it is frequently used in climate and environmental issues research, it also creates a second context for new digital design interfaces. In addition, in studies where the words "climate" and "ecology" can be followed, as it is expected that JoDLA has more subjects than IJAC in percentage. Considering their distribution by year, it has been consistently popular in IJAC over the years, especially when the word "environment" is taken as a basis. On the other hand, in JoDLA magazine, it is seen that this rate has drawn an increasing trajectory over the years. While the studies including the keywords "climate" and "change" were increasing over the years in JoDLA, this issue only took place in four articles in 2019 from IJAC.

Table 1. Context relationality over 5 years based on the main word list. (Source: authors)

Jour.	Env.	Cl.	Eco.	CC.	Year	Jour.	Env.	Cl.	Eco.	CC.
	11	-	1	-	2021		15	5	5	3
	7	-	3	-	2020		28	9	11	5
IJAC	9	4	-	4	2019	***JoDLA***	11	4	3	4
	4	-	2	-	2018		12	3	3	3
146	5	1	-	-	2017	**242**	10	3	2	2
	10	-	1	-	2016		12	1	1	1
	%31.5	**%3.4**	**%4.8**	**%2.7**	Total		**%36.3**	**%10.3**	**%10.3**	**%7.4**

3.3. Data Sorting and Extraction

For further inferences as a qualitative evaluation of climate responsive and environmental-oriented topics, relevant studies were extracted from metadata in two ways pertinent to the main and supportive word occurrences. Studies that involve 20 binary root-term occurrence combinations of these terms among abstracts were extracted, such as "*environ – climat*", "*ecolog – sustainab*", "*climat – micro*" etc. (Table 2). Binary terms are essential to select the more relevant studies considering the ambiguous term iterations like "environment." The presence of these word groups for both journals gives a general idea about the research trends. Articles were selected throughout the year, considering the binary term occurrences on abstracts (Table 3).

Table 2. Main and supportive word list with the root-terms and their binary combinations. (Source: authors)

Main Word List	Root-Terms	Supportive Word List	Root-Terms	Binary Combinations	
Ecology	ecology	aware	aware	1-environ - ecolog	11-ecolog - chang
Ecological		awareness		2-environ - climat	12-ecolog - sustainab
environ	environ	change	chang	3-environ - awar	13-ecolog - responsiv
environment		changing		4-environ - chang	14-ecolog - micro
environmental		sustainable	sustain	5-environ - sustainab	15-ecolog - efficien
environmentalist		sustainability		6-environ - responsiv	16-climat - awar
climate	climat	responsive	responsive	7-environ - micro	17-climat - chang
climatic		responsiveness		8-environ - efficien	18-climat – sustainab
climatically		micro-climate	micro	9-ecolog - climat	19-ecolog - responsiv
		micro-scale		10-ecolog - awar	20-climat - micro
		efficiency	efficien		21-climat – efficien
		efficient			

In that stage, using binary term occurrences shows that, the term "environ", short for the environment, is used mostly with "chang"(%67). In IJAC this rate is a primer, as opposed to the JoDLA. Even though this term heads upon among others predominantly, JoDLA has a more balanced focus on the terms including "ecolog" (%14) and "climat" (%11) to this. Similarities are distinctive for "ecolog" root term for both journals. While, in IJAC, "ecology-chang" association gains the highest share with %13 percent;"ecolog-change" (%8) and "ecolog-climat" (%7) are allied for JoDLA. However, "climat" rppt term highlights the significance of the synergy between "climat-chang" and "climat-micro". IJAC and JoDLA display similar measure as %13 and %18 respectively. On the other hand, even if the rates illustrate nearly identical numbers for both (%7 - %8) for the microclimatic issues, overall research counts of JoLA are far more than IJAC, as in for all binary occurrences.

Table 3. The chronological evaluation matrix of binary term occurrences through the root terms for both journals. (Source: authors)

Jour.		environ								ecolog							climat					
		ecolog	climat	awar	chang	sustainab	responsiv	micro	efficien	climat	awar	chang	sustainab	responsiv	micro	efficien	awar	chang	sustainab	responsiv	micro	efficien
IJAC (30)	2021	1	0	0	4	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
	2020	3	0	1	3	2	1	1	2	0	1	3	1	0	0	0	0	0	0	0	0	0
	2019	0	4	0	6	1	1	1	2	0	0	0	0	0	0	0	0	4	1	0	1	1
	2018	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2017	0	1	0	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
	2016	0	0	0	4	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Count/	4	5	1	20	3	5	4	6	0	1	4	1	0	0	1	0	4	1	1	2	1
	%	13	17	3	67	10	17	13	20	0	3	13	3	0	0	3	0	13	3	3	7	3
JoDLA (99)	2021	3	4	0	4	1	0	1	2	1	0	3	1	0	0	0	0	3	1	0	2	0
	2020	5	2	1	3	2	0	1	0	2	1	0	2	0	0	0	2	5	1	0	1	0
	2019	1	1	0	3	0	0	0	0	2	0	2	0	0	1	1	0	4	1	0	1	0
	2018	1	1	1	4	1	0	1	0	1	0	1	1	0	0	0	0	3	0	0	2	0
	2017	3	2	0	3	0	2	1	4	1	0	1	0	1	0	2	0	2	0	0	0	1
	2016	1	1	2	4	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0
	Count/	14	11	4	21	4	2	4	6	7	1	8	4	1	1	3	3	18	3	0	6	1
	%	14	11	4	21	4	2	4	6	7	1	8	4	1	1	3	3	18	3	0	6	1

3.4. Word Association and Network Mapping

After selecting the relevant research, one more step further, sentences were eliminated and attenuated. Including all kinds of goal and methodology information were selected by filtering keywords such as goal, aim, method, purpose, propose, etc. As a result of this process, 127 sentences for JoDLA and 61 sentences for IJAC were extracted. Thereafter as data mining phases, 3 main steps were structured: cleaning unnecessary information (1), grouping the most frequent words (2), and creating the associations (2). Firstly, the word groups in the basic sentence structure, such as conjunctions and prepositions, and unnecessary information such as place of publication, etc., were removed. In this way, the meaningful roots of the remaining words were obtained. Then, the most frequent words in the data set were grouped using the FP-Growth operator of RapidMiner. In these steps (Fig 2 and 3), all filtered word pools were firstly translated into text for cleaning, then binomial values (0 or 1) to acquire word occurrences for all selected sentences. Results of this step were calculated with FP-Growth operator to obtain support values regarding occurrences values. At the same time, the association rules between the words were analyzed with the association rules operator [27]. Network mappings were created for both journals, considering the association rules and supporting values of binary comparisons of words from the data set. These associations were visualized regarding color codes, link thickness, node positioning and size via a web-based network mapping interface named Graph Commons [14]. In association with rule creation, data mining was run using word stems. With this attempt, some words emerged such as comput, simul, creat, or chang sourced from various word clouds such as computerization, computability, simulation, change, creation etc. These words were illustrated as the most common meanings with association rules translated into connection forces in keyword network mappings.

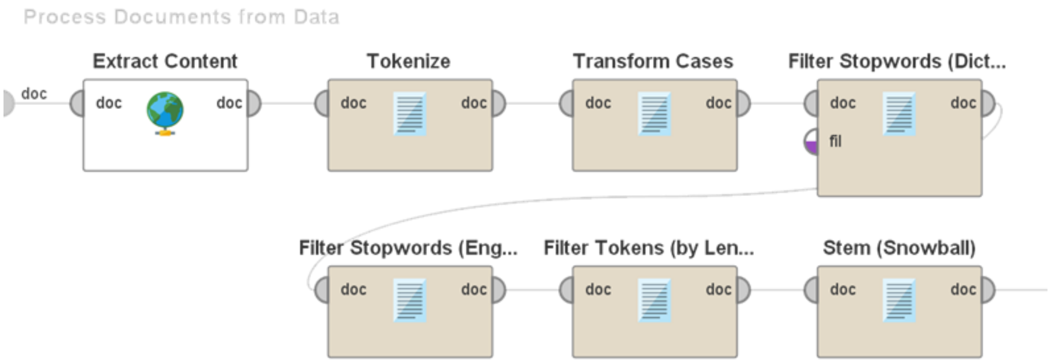

Figure 2. Cleaning the unnecessary information among word pool of all selected goal sentences. (Source: authors)

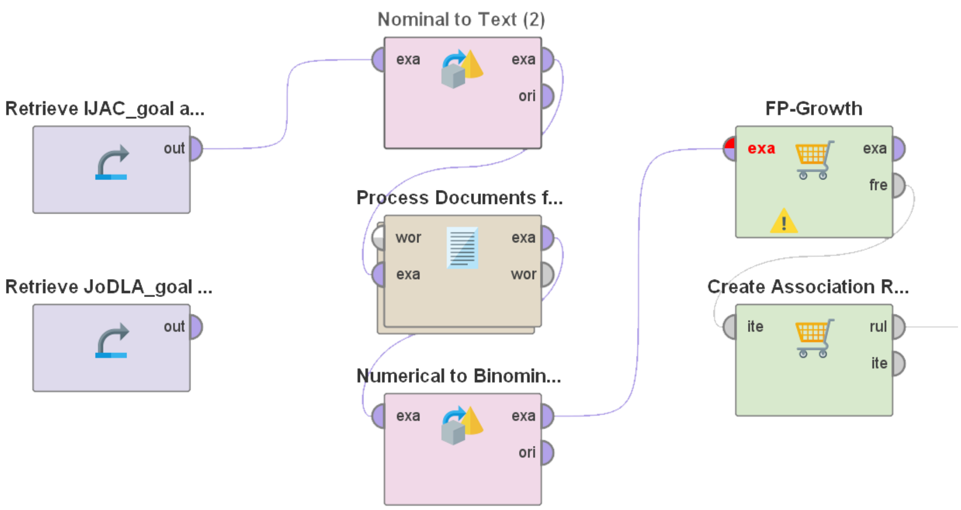

Figure 3. Overall synthesis including translations, word grouping and association rules with support values of FP-Growth. (Source: authors)

4. RESULTS

Considering both journals' depth of keyword variations and their relational graph, the main drivers which stood out were data size and variety. The proficiency in the computational approaches and environmental-focused methodologies among disciplines has significantly shaped the relations. Due to these issues, the most repeated and related notions formed the focal center. As the repetition of keywords and their relationship with the main topics decreases, it pulls out of the center of network mapping. It was observed that some concepts such as model, fabrication, and material have shaped the center. These concepts are associated with orbital concepts such as application, process, environment and project. The supporting concepts in the orbital sphere have different degrees of relationship with the other leading concepts. In association with rule creation, data mining was run using word stems.

In JoDLA, dominant words were "model", "simulate", and "environ". However, when the first data was run and illustrated according to support values, the "method" term shaped the whole network. Nevertheless, the "method" term remains ubiquitous. A manual evaluation was made to disaggregate the research to see if it introduces a method or uses a defined one. By this means, the terms that were repeated in 32 sentences, which belong to 9 different studies, were eliminated out of 127. According to the final network mapping of JoDLA (Figure 4 and 5), "model" got the highest value with 0.213, followed by "propose" with 0.164. These keywords have been repeated respectively above 21% and

%16. On the other hand, it can be seen that the highest support value of IJAC is incompatible with the network mapping trajectories. Even though the "method" keyword was ranked as the highest support value at 0.249, after the "comput" related to the computation and computing variations, it fell behind the "fabrication" and "material" in network mapping. The difference rests on the evaluation method, which focuses on the keyword repetitions and combinations of multiple occurrences in various keyword groups. Therefore, although the support values of "fabrication" for IJAC or the "environment" for JoDLA were not high, they formed important nodes in network maps due to their intense connections with various nodes. On the other hand, it can be said that the word "method," which has the highest support values in IJAC's network mapping, was overshadowed by the relations between the words "comput" and "fabrication" with other words. Even though the "method" keyword was ranked as the highest support value at 0.249, after the "comput" related to the computation and computing variations, it fell behind the "fabrication" and "material" in network mapping. The difference lay on the evaluation method which considers not only term occurrences but also combinations of various binary relations for each word. In this manner, despite the support values, specific words were highlighted as nodes like "fabrication" for IJAC, and "environment" for JoDLA.

Consequently, the scope of JoDLA is more focused on climate and environment-oriented approaches, which are heavily nourished by intertwined concepts such as "environment", "model-nature", "urban-biotop" or "simulate-hydrolog". These complex relations are shaped by the main node of "model" and supportive nodes such as "develop", "propose", "simulate", "process", and "environment". It can be deduced that the research focuses on developing a new model proposition with new tools, software, algorithms, or simulations. Especially "model" oriented research shares the links between computational and design-related innovative tools and applications. Although expected, there is no direct link between "environment" and "model". This connection was established only with the word "simulation". The critical point here is that it can be argued that the term "environ," which has only one connection with the word "ecolog", does not come close to the main focus of research. The "simulation" keyword shares a strong relation with coastal research regarding different erosion and water levels in hydrological investigations. Also, new tools and software come to the fore for urban landscape research, specifically for predicting future projections.

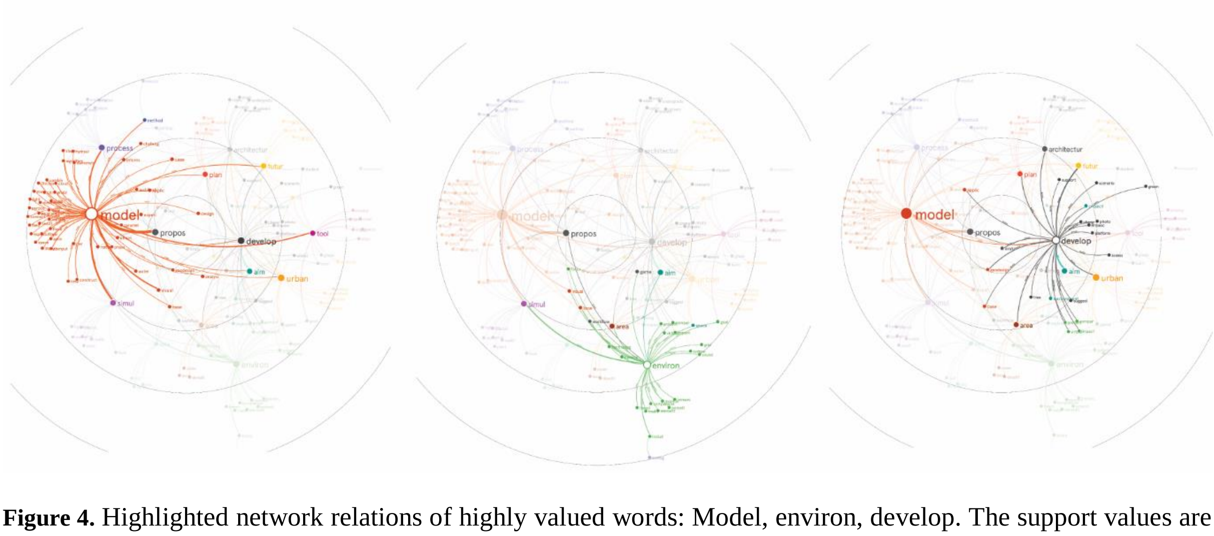

Figure 4. Highlighted network relations of highly valued words: Model, environ, develop. The support values are 0.213, 0.134, and 0.126, respectively. (Source: authors)

According to the word "environment" constitutes an essential node in all research regarding both repetition and multiple relationships. When examined with its sub-words, it can be said that the studies fit into two different contexts. One of these contexts is about the combination of words such as "immersive", “interact", "human", "virtual", and "augment." This combination concludes that the most current topics, such as interactive environments as an interface, are included in the research. The other one is about "measure" and "potential." It can be said that it forms the context of environment-oriented research based on "tools" such as "space" and "data."

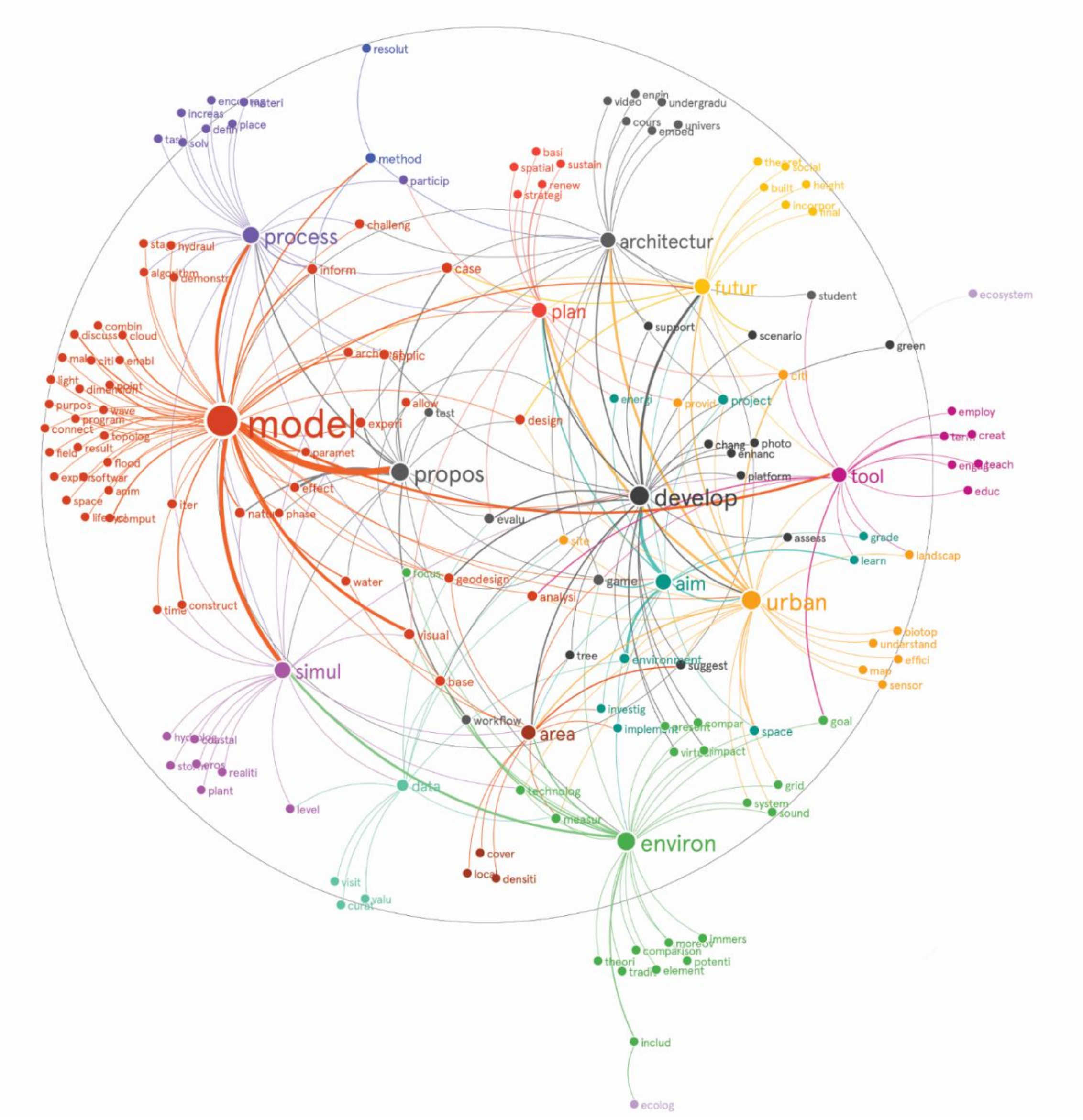

Figure 5. Keyword network mapping of JoDLA. (Source: authors)

In IJAC's network mapping (Figure 6 and 7), dominant keywords stand out as "fabrication", "compute", and "material" at first glance. Similar to the previous mapping, despite their support values and important nodes in network mapping showing a correlation, their importance varied. When the item list support values were evaluated among all keywords in IJAC, "method" got the highest value with 0.249, followed by "compute" with 0.180. Also, "fabrication" with 0.180, "material" with 0.131, and "process" with 0.098 follow after, even though they are overruled in the network mapping. In particular, it can be said that the computational approaches that focus on climate and environment-oriented research in the lense of architecture, are mainly grounded on new material production, new construction techniques, and mechanization techniques developed for this purpose. Keywords such as "robot", "fabrication-manufacture", "fabrication-structure", "material-print" and "compute-aid" form the basis of this inference. Moreover, considering the relationships of the keyword "process", which has close ties with "fabrication" and new "material", related to words such as "novel" and "neural network", and "machine". It is seen that current methods such as artificial intelligence and machine learning are studied in specific areas. When going from the center to the orbits in the relationship map, it is seen that keywords such as "artificial" - "intelligent" and "deep" - "learn" appear in two separate groups concerning these issues. When these examples are examined on an article basis, it can be seen that studies are focusing on climate change and environment-oriented design, such as disaster-shelter design. However, similar research including words like "nature" and "environment" are used in different contexts.

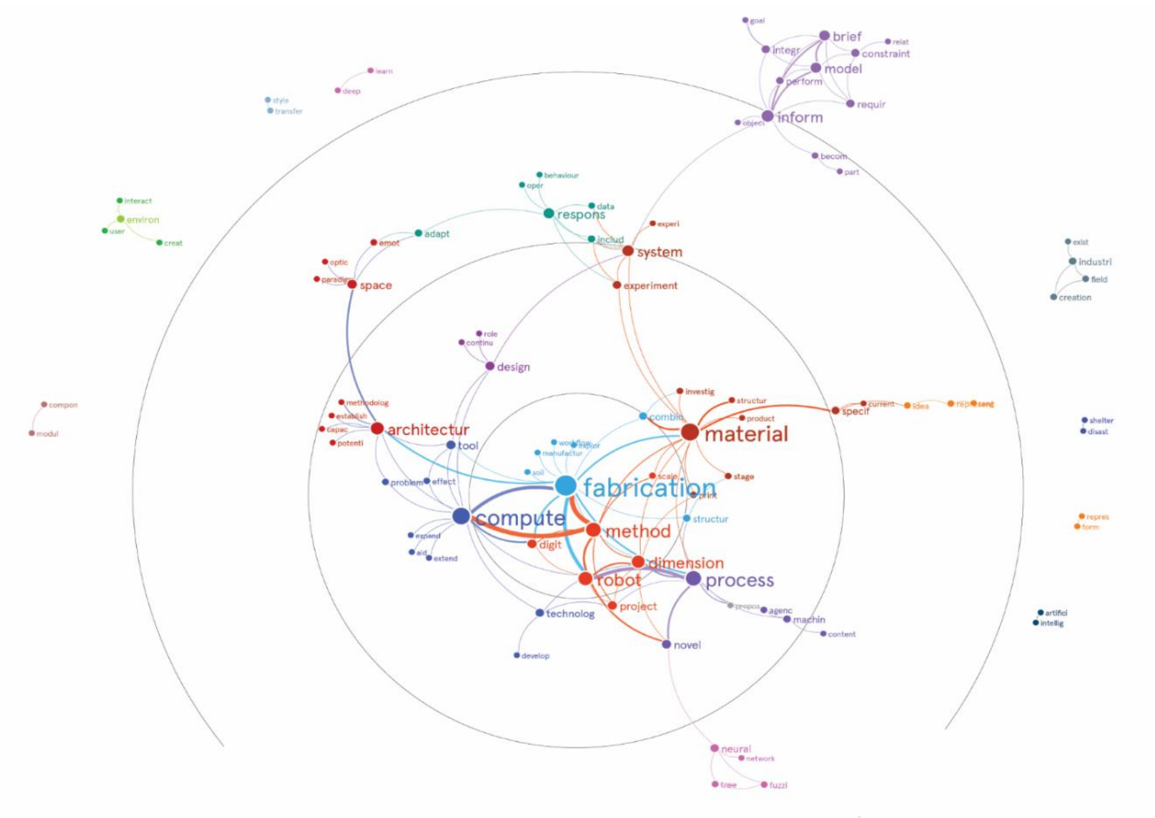

Figure 6. Keyword network mapping of IJAC. (Source: authors)

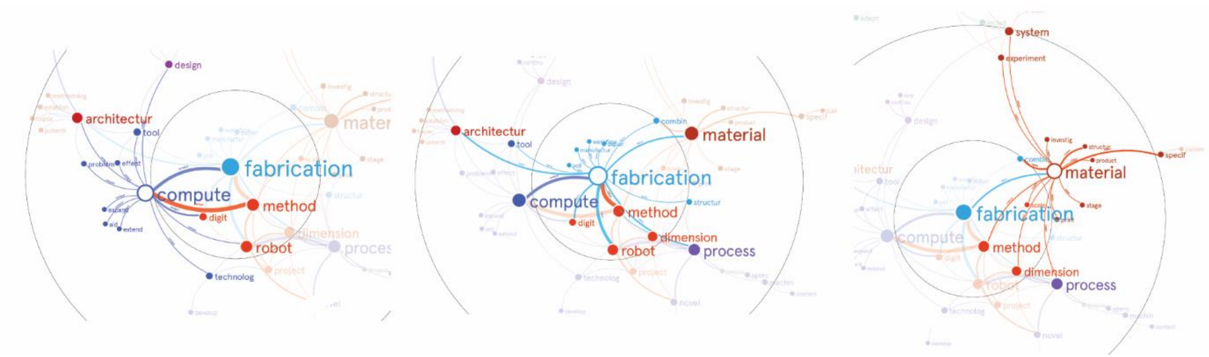

Figure 7. Highlighted network relations of high-rated words: Compute, fabrication, and material. Support values are 0.180, 0.180 and 0.131 respectively.

4. CONCLUSION

General inferences can be made for both journals when the obtained network mappings and quantitative comparisons are evaluated holistically. This evaluation discusses the correspondences and incongruities of digital approaches and notions of environment-oriented design in both disciplines. It can be said that inferences are made for both disciplines, especially in terms of digital and computational techniques and approaches to deal with climate and environmental issues. In this way, interpretations were obtained regarding how both disciplines deal with climate and environmental issues, especially through digital design and computational approaches. Although research approaches in architectural design focus much more on digital fabrication and building material, different specialized subjects have also been studied.

In landscape architecture on the other hand, it has been seen that the subjects which are encircling around new design models and simulation techniques as methods are closely related to each other. By the top-down methodology of the research, differences were obtained regarding general approaches to climate and environmental research. In particular, it has been found that both disciplines work on environmental issues from the context relationality stage. Also, the contextual query of the word "environ" was examined in terms of its relations with computational approaches in the association network mapping stage. Then, by the binary-term occurrences, even though it has been seen that the landscape discipline generally relates to these issues more than the discipline of architecture, the differences were not as high as expected. The significant point is that JoDLA's "climate-change" binary review has increased since 2017, while IJAC's special issue focused on resilient design and accordingly climate matters in 2019. Nevertheless, considering the close relations with environmental and climate issues in the landscape architecture discipline, the specialization was not high in terms of computational approaches regarding architecture.

CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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THE DEVELOPMENT OF INTERNET WEB 1.0 TO WEB 3.0 AND ITS EFFECTS ON ARCHITECTURAL EDUCATION

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ABSTRACT

The World Wide Web has quickly become one of the primary resources of information that comes to mind for many people in many fields. The development of the internet, which has more and more application areas, is grouped as Web1.0, Web2.0 and Web 3.0. Today, the web, which started with Web 1.0, has become a virtual world where people can actively participate. With this development of technology and its effect on every aspect of our lives, educational practices have also begun to change. Especially with the pandemic, the tools of Web 2.0, online learning opportunities, internet resources and communication platforms have been better understood and started to be used more efficiently in education. Architectural education, like many other fields, has been affected by the spread of the internet and its being a source of information. In the light of these data, the study focuses on the reflections of the learning opportunities and resources that have developed with the internet on today's university students. For this purpose, formal and informal online internet-based learning environments examined in this study. In order to collect data in the research, an online internet survey prepared and applied to a group of architecture and interior design students within the limitation of Eskişehir Technical University. Questions were asked about expanding resources, tools, deficiencies in education and what their dream education is like. In the study, the evolution of the internet, the changing needs of architectural education, the offers and demands of teachers and students in different generations, students and the evolution of the internet were investigated by considering generational differences. As a result of the study in which 47 students participated, the current state of architectural education was determined from the eyes of the students in the light of the answers given.

Keywords: Web1.0, Web2.0, Web 3.0, Architectural Education

1. INTRODUCTION

In recent years, Internet is one of the main sources of information where it can be accessed rapidly. Today, the internet is in every aspect of our lives. The development and change experienced by the Internet are also classified as Web 1.0, Web2.0, Web3.0 and Web4.0. Web 1.0 describes the period in the early days of the internet, when the contents on static web pages were read like newspapers or books and the interaction was one-way [1]. Web 2.0, is describes a situation in which communication is versatile, the internet is the follower and guide of social life, and the user becomes a productive content producer, not passive. Web 3.0 refers to an internet where the user reads, writes and manage. It is predicted that access to information will be faster, easier and error-free in Web 3.0, which is built on semantics, artificial intelligence, block chain and cryptology, 3D experiences and games, spatial web, digital copies and decentralized structures. It is envisaged that the interaction to be established with the Internet Web 3.0 will be beyond the screens of computers or mobile devices, in 3D environments supported by virtual and augmented reality, in environments where all senses of the human can be involved and where speaking and touching can be used as easily as seeing and hearing [2]. It is not possible to make a clear date and distinction in determining the development status of the Internet. The process continues with an evolutionary change, and the rate of change and the impact area in different areas are also different. Today, it is possible to see Web 1.0, 2.0 and 3.0 applications together. Web 4.0,

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on the other hand, is still experimental. Web 4.0 is defined as a symbiotic network in which the human mind interacts with machines [3].
While the development of the Internet continues at such a rapid pace, the way generations perceive and benefit from this development shows differences. In recent years, there are many studies investigating the differentiation in terms of values, attitudes and characteristics among human communities that were born in different periods and experienced technological developments in different ways[4]. Events, tendencies and developments in the life span of people born in a similar time period (15 years at the upper limit) can change the attitudes and behaviors of people[5]. When classified in the social dimension, it can be said that these generations, called the X, Y and Z, have experienced the most remarkable technological changes. For X generation, television and telephone were indispensable technologies, who were born between 1965 and 1980, they met mobile phones and the Internet when they lived in their twenties and thirties. Generation Y, born between 1981 and 1996, witnessed the development of the internet and the inclusion of mobile technologies, and experienced the development of social networks in their childhood and youth. Generation Z, who was born between 1997 and 2012, and is also in their twenties today, is living a period in which social media has completed its development and is a full part of life and has become indispensable with the freedom provided by mobile technologies. The acquisition and transfer of knowledge has gained great momentum and changed, especially in the last 30 years. Three different generations, who experience the internet in different ways, also have differences in the way they use the internet. It was also different for these different generations to include the Internet in their education. The potentials of the internet in the field of education have evolved over time. Differentiating internet usage habits of generations have also affected this situation. In today's world, where the internet is perceived as one of the main sources of information, the reflections of internet development in education are also an important issue that needs to be examined. In this scope of study, the resources used by the active web user generation Z were investigated. Moreover, opinions on the deficiencies of today's education and the provision of a better education have been obtained.

1.1. Reflections of Web Development on Education

Development of web has affected education in different ways in every period. **Web 1.0** was the first implementation of the web and it lasted from 1989 to 2005[6]. It was referred as the first generation of World Wide Web, which was defined as “read-only” Web. It was the static pages and content of the era delivery purpose only. In other words, the early web allowed us to search and read information. It did not offer people anything different from books. One of its most important features was that it created an online presence and make their information available to anyone at any time.

Web 2.0, on the other hand, allowed users to provide content and interact with other users and radically changed the appearance of the internet in a very short time [7]. With Web 2.0, the internet itself has become a learning platform. These platforms have provided the innovative learning opportunities of Web 2.0 [8]. With Web 2.0, the concept of e-learning and learning environments defined as learning 2.0 have emerged. Web 2.0 technologies and contents can be summarized as social bookmarking, wikis, shared document creation, blogs, microblogs, presentation tools, image creation and editing, podcasts, audio use, video editing-sharing, screen recording, mind mapping and digital storytelling [9]. It briefly explains these contents of Web 2.0, first of all it is to start with wikis. Wikis are one of the most used Web 2.0 technologies. Many wiki tools like Wikipedia, Pbwiki Wikispaces etc. are free and available to everyone. Wikis allow educators to not only organize and interrelate information for their students, but also more importantly allow students to co-construct knowledge [9]. Social bookmarking is used to share liked web pages with others. Shared document usage tools allow users in different places to make edits and write comments on the same document. Google Docs, Writeboard, and Buzzword are good examples. Blogs allow individuals or groups to share, rate, and organize information on the web. Microblogging tools such as Twitter enable instant communication and follow-up of events. With Web2.0, presentation tools have also started to diversify. Apart from Microsoft PowerPoint and Apple's Keynote, different online alternatives of presentation have started to be used. Software such as CoolIris, Prezi, Slideshare, Vcasmo provide opportunities for non-linear organization of information that can be directed in multiple directions at various scales, and for sharing different multimedia. Image creation and editing programs allow the online drawing and sharing of diagrams such as flowcharts and architectural drawings. Podcasting and the use of audio, on the other hand, gave people the opportunity to make sound recordings and share them easily. The exchange and use of video has become a mainstream phenomenon in recent years. It is possible to find a video on every topic, especially on YouTube. Video is an especially effective way of representing procedural information, as it provides a synchronized flow of audio and visual information. Screen-recording software can create a powerful mechanism when shared online using sites like YouTube. Learning contents created for various software are made with screen recordings. Mindmapping and digital storytelling platforms encourage people to present important elements of a concept, idea or reflect on their relationships. These can also help develop different understandings of the problem.

In order to understand the educational potential of Web 2.0 technologies, it is important to examine and understand the possibilities they offer to users. These possibilities are: 1) Presence, 2) Modification, 3) User-generated content, and 4) Social participation [10]. Presence is to ensure that Web 2.0 users are active in that environment through their profiles, identities or avatars. The active presence occurs when the user updates, interacts with other users. Modification refers to allowing users to customize their profile pages. User-generated contents refer to the fact that users both produce and consume them. Social participation means that the content produced and consumed by the users makes them social participants. Although the platforms and potentials that Web 2.0 provides for education are grouped in this way, initially Web2.0 environments were not designed for educational purposes. Their educational potential has been discovered and spread over time. The distance education process experienced with the COVID-19 at the end of 2019 and the inclusion of the potentials of the Internet in formal education has accelerated. In recent years, the high potentials of Web 2.0 platforms in formal education, adult education and distance education have been discovered, and many studies have been carried out in these areas [8–14].

Web 3.0 is defining as intelligent web or semantic web with technologies like cloud computing, 3D visualization, artificial intelligence, big data, augmented reality and more. It makes passive learner into active learner in the learning process [3]. Today, Web 3.0 and Web 2.0 technologies are used together. On the fact that Web 3.0 active learning systems are not yet concentrated in learning environments, the study will investigate the effect of Web 2.0 on learning environments. The study focused on the effects of web development, Web 2.0 and technology on architectural education.

1.2. The Change of Architectural Education with the Effect of the Internet

The development of the web has also shown its effects in the field of architecture. With Web 1.0, websites, that are accessible available to anyone at any time, have also emerged in the field of architecture. With the help of these websites, current projects, competitions and theoretical discussions in the field of architecture can be followed worldwide. This information on the internet have also been a reference source for architectural education. With Web 1.0, architectural resources have become accessible and up-to-date for everyone. Architecture schools from all over the world have had the chance to incorporate up-to-date knowledge into their education system.

With Web 2.0, architects had the opportunity to exist and comment on websites that are sources of information, to produce content about their own projects, and to take part in discussions on current issues. It has provided an opportunity for those who practice the discipline of architecture, educators and students to come together easily. The Internet has become a platform that brings together different professionals and amateurs in the discipline of Architecture. Web 2.0 have enabled not only information source and communication, but also important lectures in architectural education to be carried to the internet in an interactive way.

Today, online resources and e-learning methods have an important role in architectural education. Many platforms allow students to interact with peers and lecturers [15]. Research on the potential of using social media-based learning in design education supports this idea. There are many studies where social media platforms such as Facebook are actively used in design studios[12,13, 16,17]. This is supported by the intensive use of computers in architectural design practices. There are studies investigating how the integration of Web 2.0 tools into learning inside and outside of education can be handled within the framework of the architecture discipline [15,18,19]. The adaptability of Web 2.0 applications for education has emerged even more creatively during the COVID-19 pandemic. This uncertain and sudden development with COVID-19 has created an environment where the compatibility of traditional architectural design studios with distance education models is questioned.

Web 3.0 opportunities are being tried to be integrated into architectural education in this time more. Virtual reality, augmented reality and game technologies become more important and critical. It is possible to see that it benefits from some technological infrastructures used in computer games in architectural research [20–22]. It is not known what resistance and support the innovations that will come to our lives with Web 3.0 and Web 4.0 in the near future will encounter.

2. MATERIALS AND METHOD

The study was designed as a qualitative research. A survey consisting of open-ended questions was preferred. First, it is planned as a process that includes data collection and coding (data analysis). Open-ended questions are questions that do not provide participants with a predetermined set of answer choices, instead allowing the participants to provide responses in their own words [23]. For this reason in the study, students were expressed themselves in their own sentences and to answer in the length they wanted. In the study, open-ended response formats adopted, and the data collection process was built on noninteractive way[24]. An online internet survey was applied and no interaction was made with the participants. Within the scope of the study, this method was preferred so that they could freely evaluate their web usage and education processes and be more comfortable and critical, and limited demographic information was requested from the participants. For participants, architecture and interior design students were selected. It was expected that students' awareness of methods, resources and educational processes would be better. For this reason, students in 3rd and 4th grades were chosen as survey participants.

The open-ended survey carried out within the limitation of Eskişehir Technical University. The study is a pilot study to determine what kind of resources today's architecture and interior design education uses, and what the reflections of the development of the Web are on education. 47 students, 25 (M:8, F:17) architecture, 22 (M:5, F:17) interior design students, participated in the survey. All of the participants who are in 3, 4 or more years of undergraduate education are born between 1995-2001. 8 open-ended questions directed to architecture and interior design students were discussed mutually within the framework of the answers they gave. The questions asked were grouped under three main headings. First group resources, tools, and methods in education. Five questions were asked in this group. Most of the answers given by the students in this group were common, the results were evaluated qualitatively in order to be more understandable.

Second group is related to deficiencies in the inclusion of technology in education. Two questions asked in this group. Last group is about the technologies they imagine and see potential are the questions asked. The answers given in these two groups were divided into themes and evaluated with illustrative quotations.

3. RESULTS AND DISCUSSION

3.1. Resources, Tools, and Methods in Education

In this part, five questions were asked to the participants in order to identify the resources, tools, methods and platforms that were expanding in the architectural education. **First of all,** it was asked which websites and social media platforms they used for to take information about the educational processes, research, keep up to date with architecture, examining the sample projects, etc. The answers given to the question in which the participants could give common answers by both groups are shown in Figure 1 as the number of answers from the number of participants and websites.

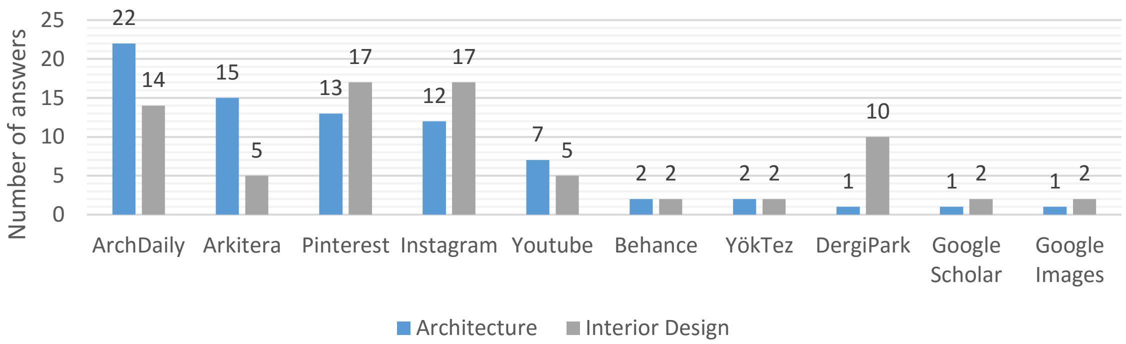

Figure 1. The answers given to the question of the internet resources that Architecture and Interior Design students use in their undergraduate education (figure source: author)

The answers given are examined, we see that the most basic resources for architecture students are ArchDaily, Arkitera, Pinterest and Instagram. For interior design students, we can say that Pinterest and Instagram are ahead of ArchDaily. In addition, we can say that interior design students use DergiPark more as a resource in their studies. For architecture students stated that they also benefited from sites such as Arkiv (6 participants), Twitter (3 participants), Mimarizm (2 participants), and Reddit (2 participants). In the study, e-book (1 participant), online access journals (1 participant) or digital library (2 people) were written as a resources.

The fact that social media platforms such as Instagram, Twitter and Youtube have become a source of information is based on the shares made by professionals in these fields and the social media accounts of the preferred websites. It has been stated that ArchDaily, Pinterest and Instagram are used specially to examine the images of sample projects, while resources such as DergiPark, YökTez, Google Scholar are used to obtain information about the architectural project.

In the second question, it has been investigated in which courses and for what purposes internet resources are used. When the answers given are examined, it is seen that these resources are used extensively in the project courses. According to the answers of the architecture students, 72% (18 participants) used internet resources in project courses, 13% (3 participants) in urban design courses, and 6% (1 participant) in construction courses. %9 (3 participants) of them stated that they used internet resources in all courses. In interior design students answer, 50% (11 participants) used internet resources in project courses, 33% (7 participants) in Furniture design course, and %17 (3 participants) of them stated that they used internet resources in all the courses.

The fact that the courses, which are the basic courses of architecture and interior design education, and the answer to 'all of the courses' came to the fore, show that internet resources are included in every process of formal education.

In the third question, the participants were asked which devices they use more for projects, assignments and exams in their undergraduate education. While all of the participants stated that they used computers, it was seen that the computer and mobile phone options were mostly given together. All of the students of the architecture gave the computer answer. In addition to the computer, mobile phone (92%, 23 participants), tablet (20% 8 participants) and printer (8% 2 participants) responses are also given. All the interior design students gave the computer answer too. In addition to the computer, mobile phone (86%, 17 participants), tablet (23% 5 participants) and virtual reality glasses (4% 1 participants) responses are also given.

Computers have an important role in architecture and interior design education. Design, drawing, presentation etc. used effectively in many situations. The fact that mobile phones are an important tool can be dated to a short time ago. Programs developed with smart phones are in an important position for education. Due to their advantages such as internet connection, ease of sharing and communication, easy portability and accessibility at any time.

In the fourth questions, considering that communication between students and educators has an important in design education, it was asked which digital platform, applications or social media tools they used to communicate with their friends and lecturer. According to the results summarized in Figure 2, Whatsapp, Instagram, Zoom are the prominent answers. Responses were also received from the participants, such as Trello, AirBridge, Canva, Microsoft Teams.

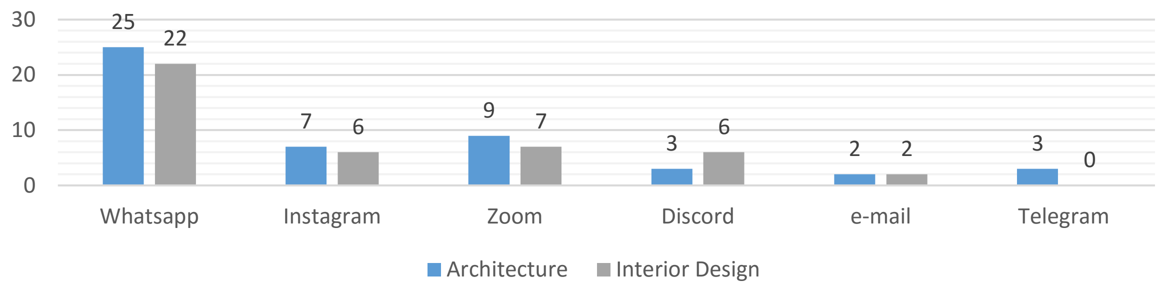

Figure 2. Resources used by architecture and interior architecture students for communication in their education (image source: author)

Participants, who stated that Whatsapp groups were established for many courses, provide instant communication with these groups. It is thought that the images, comments or opinions shared in these groups contribute to the educational processes of the students.

Finally, the participants were asked which drawing and modeling programs they used and how they learned about these programs. The most used programs are summarized in Figure 3, and the learning methods for these programs are summarized in Figure 4.

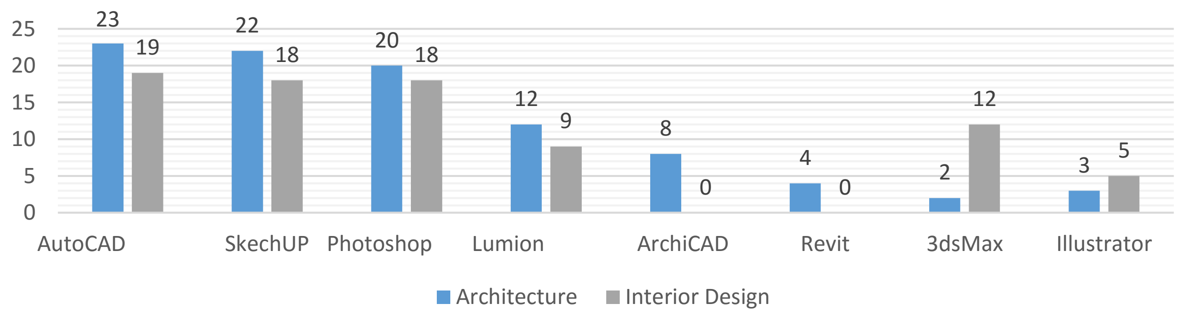

Figure 3. Programs used by Architecture and Interior Design students in their education (image source: author)

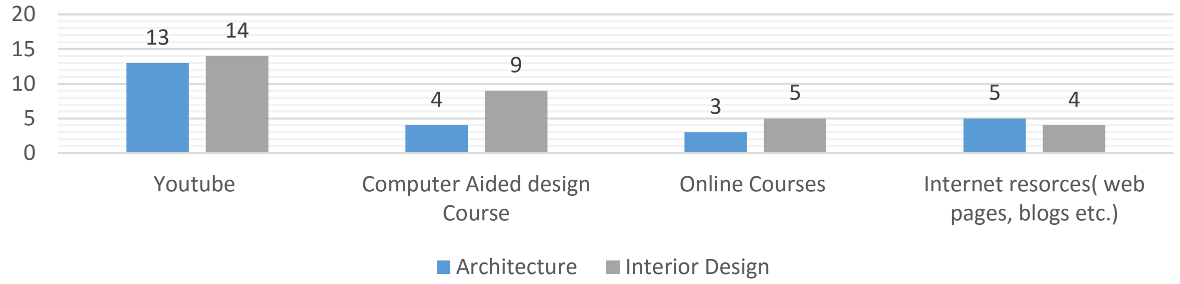

Figure 4. The resources from Architecture and Interior Design students learn about the programs they use in their education (image source: author)

It was seen that both groups use AutoCAD, SketchUp and Photoshop programs intensively. Most of the students learned the programs using YouTube or online learning platforms and internet resources. In this sense, it was seen that Computer Aided Design courses are supported by internet resources and even got behind.

It is seen that the internet and technology are actively used in many places such as obtaining information, program competence, communication in architecture and interior design education.

3.2. Deficiencies in the Inclusion of Technology in Education

In this part of the study, the participants were asked about the deficiencies they felt while doing research on the internet, whether their undergraduate education was sufficient to follow current technologies, and the problems. It can be grouped as the lack of resources and qualitative problems, the difficulty to find Turkish resources, and the difficulty in finding reliable sources. Explanatory quotations and themes are given in Table 1. The open-ended answers were grouped according to the themes, and the identified themes were supported with explanatory quotations.

Table 1. The answers given by the students on the deficiencies they felt while doing research on the internet.

Deficiencies	Architecture students Illustrative quotations	Interior Design students Illustrative quotations
"Internet resources are few and have qualitative problems"	"I have difficulty in reaching project details." "Drawings that need to be studied in detail can be of low image quality."	"Project details are hard to reach... I can't find quality details." "While doing research on a site, sometimes healthy results do not come out depending on the keywords."
"Difficulty in finding Turkish resources, foreign language problem"	"Inability to reach correct information due to lack of Turkish resources" "Lack of Turkish content about some programs."	"Foreign channels videos are getting better in this regard; Turkish channels have deficiency. Turkish resources are insufficient" "The language of the required sources is not Turkish."
"Difficulty in finding reliable sources"	"Too much misleading and unclear information. Limited and inaccurate access to correct information" "Too many irrelevant answers"	"I can't find enough reliable sources when researching. The resources I can find while doing research are very limited and informational."

In the study, the participants were asked whether the undergraduate education was sufficient to follow the current technological developments. And it was requested to indicate the deficiencies observed. The answers given are examined, the majority of the participants find their education insufficient in terms of following the technological developments. 55% of these answers stated in a negative way that they found it insufficient. On the other hand, 19% of the participants think that their undergraduate education is sufficient to keep up with the latest. Other answers have a recommendation rate of 26% and focus on deficiencies and what needs to be done. This group is classified as undecided. When the answers given by architecture and interior design students are compared, architecture students find their education more inadequate. The answers are summarized in Table 2 with explanatory quotations.

Table 2. Responses on whether the Undergraduate Education is sufficient to follow current technologies.

Opinions	**Architecture students Illustrative quotations**	**Interior Design students Illustrative quotations**
"Participants who found it insufficient""	"No. They do not do exciting activities that will encourage learning. But competence is also expected from the student." "Undergraduate education is insufficient to follow technological developments. Information from years ago is always presented in the lessons." "I think it is an education based on the past rather than the future use of architecture in technology"	"I don't think it was included. More opportunities should be offered. Technologies such as artificial intelligence, virtual reality and augmented reality should be included more often." "I don't think it was included. New developments, competitions, new projects should be included more."
"Participants who found it sufficient	"Yes, I think it was included"	"I think it is enough because all of our professors are researchers and competent."
"Undecided participants"	"Teachers have an effort towards these technologies, but I don't think it's enough." "Some software's are taught, ready answers are given to us, however, when I encounter a problem in these environments while designing, I discover myself how to find a solution to it, most of the time, I feel like there is a superficial technology approach."	"It is partially included, but there are so many technological developments today that we are not fully taught or followed." "We use technological tools such as computers, but we cannot use the latest technology (such as 3d printers, VR glasses)."

3.3. Technologies That Can Make Architectural Education Better

Finally, the participants were asked a question about the technologies that you think will make your undergraduate education better quality, and the education of their dreams. With this question, it is aimed to determine the foresights and expectations of the participants. The answers given by architecture and interior design students are united in the theme of "virtual, augmented and extended reality technologies".44% (16 participants) think that virtual reality and augmented reality technologies should be included in their education. The opinions of the participants are given in Table 3.

Table 3. Responses on technologies you think will make your Undergraduate Education better.

Featured theme	Illustrative quotations
"Virtual, Augmented and Extended reality technologies"	"It could be virtual/augmented reality. We can examine our projects and designs better. During the design process, our instructors put a lot of emphasis on the experience in the space. We can better understand this experience with these technologies and transfer it to our designs." "Virtual reality applications can be included. It can be very enjoyable and instructive to experience our projects and the spaces we design with virtual reality glasses." "Virtual Reality technology can add quality to education during the creation and presentation."

3.4. Discussion

In the light of the questions and answers asked to the participants within the scope of the study, we can say that architectural education has many extra resources apart from its formal resources. It is seen that the possibilities of Web 2.0 are used in this sense. It is seen that the Z generation participants are aware of and demand Web 3.0-enabled applications such as augmented reality, virtual reality, artificial intelligence, machine learning, and Metaverse. The prominent comments in the light of the answers given at the end of the study:

- The potential of Internet resources, which are mainly used for project courses, which is the basic course of architecture and interior design departments, should be investigated for other courses as well. It should be researched which websites can be helpful and supportive resources for which courses.
- In the study, it was seen that mobile phones are one of the most actively used tools. This shows that mobile phone active learning methods can be used easily in education. It should be considered that especially augmented reality and virtual reality technologies can be used actively on smart phones should be increased.
- Online communication platforms, which enable the communication of students and instructors and whose importance is better understood with the pandemic, can be changed according to the course. The full potential of these environments should be investigated.
- An important point in the study that should be underlined is the difficulty in finding reliable sources, although the internet is a resource in many areas. Considering the information pollution in the internet, it is necessary to find reliable sources, reference checks, bibliography review, etc. Students should be informed about the issues.
- The problems experienced in finding Turkish resources can be explained by the inadequacy of foreign language education specific to the university. However, many projects made in the departments of architecture and interior design are not published on the internet. At this point, in addition to making use of internet resources, producing internet resources is an issue that needs to be addressed and thought about.
- One of the themes that stand out among the inadequacies in the follow-up of current technologies is the progress of education depending on the past and away from the current. Educators need to follow current developments and include them in the lessons.

- In the study, it was seen that students especially wanted to experience virtual reality and augmented reality in their education. Studies on virtual reality and augmented reality technologies should be done in departments and deficiencies should be determined. It is an issue that needs to be investigated how much potential studies on these technologies have for which courses.

4. CONCLUSION

The close relationship of architecture with digital technologies does not reflect architectural education. Changes in the internet, which is now the center of information, communication and interaction, contain more potential for architectural education than in many other fields. The educational environment has expanded with the possibilities of the Internet. In the study, it has been seen that the internet is an important resource in many fields of education, even in a limited participant universe. Also according to this study; the internet has an important place in many subjects such as resource research, learning software, and educator-student or student-student communication. It has been seen in the distance education process during the pandemic period that connections between students and educators can be provided without being connected to the school, thanks to different internet sites and educational resources. In this context, the effect of school, which is one of the three components of formal education, has become questionable. The increase in educational platforms and resources and the fact that students are exposed to information at every moment of their lives through the internet have made the student-educator relationship more interactive. In this situation, where both sides will transfer information to each other, it shows that we are in a period where the educator is not only the main source of information, but one of the main sources of information. With the internet, educators become more open to current interaction. As a result of the study, ideas were obtained on the tools, learning methods, and websites that are the source of education of the generation who spend most of their time with the media and devices that connect to the internet. Considering that Web 3.0 opportunities will enter our lives and education in the near future, we can predict that the student expectations obtained in the study may be realized in the near future. It is important to increase the number of similar studies and to determine the positive and negative effects of the internet and the potential of technologies in architectural education.

CONFLICT OF INTEREST

The author(s) stated that there are no conflicts of interest regarding the publication of this article.

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OUTPATIENT CLINIC DESIGN THROUGH RULE BASED DESIGN METHODS

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ABSTRACT

Health is one of the basic needs of humanity. People use hospitals to control and treat their health. As the most advanced health structures, hospitals have been transformed with new requirements and systems throughout history. Health structure design contains various inputs, data, and criteria. This study reveals the network of relations with a rule-based design method to provide systematic design assistance for architects. Hospitals have complex structures in terms of the design solution and production management. Therefore, it will be useful to systematize these complex structures for design inputs to create a base for the architectural program. Within the framework of this study, rule-based design approaches were adopted for hospital polyclinics. Polyclinics work independently but are linked to the main hospital system. Today the main design problems in polyclinics are accessibility and visibility. The main purpose of this study is to create a model base for alternative plan types by taking advantage of the productive method: rules-based design. Firstly, to consider the functional relations and distances among multiple units for an optimum solution, the study evaluates the existing working designs and their derivatives. Secondly, it addresses the optimization of hospital polyclinic design in terms of obtaining the minimum route overlap, minimum walking distance, and high visibility of the patients in the polyclinics. Thirdly, due to the repetitive nature of polyclinic spaces, the space grammar method has been used as a rule-based approach for the derivation of spaces. The genetic algorithm method used together with the shape grammar is included in the study to process the formal and numerical data and to compare the original design alternatives. The spatial sequence technique of Space Syntax is used as an evaluation method. In the mixed method of this study, the relational information obtained from existing hospitals has been resolved. These relations have created design rules for an outpatient polyclinic architectural program by binary and triplet relations. Alternative productions with the genetic algorithm tools have been generated through the Rhino / Grasshopper software extension. The generated plans have been evaluated with the spatial sequence technique of Space Syntax theory to explore optimum solutions for distance and visibility.

Keywords: Architectural design, Genetic algorithm, Space syntax, Outpatient clinic design, Shape grammar, Rule-based design

1. INTRODUCTION

Health is one of the basic needs of humanity and enables people to continue their lives unhindered. Health care is a right for everyone to maintain his/her life in international law and the constitutions of countries. Health rights are provided to patients through hospitals with health services. As important health structures, hospitals are like living organisms consisting of many health care compounds. Although many health institutions like health centers, local health centers family planning centers and laboratories exist in Turkey, hospitals are at the top of the most-used health institutions. They are included in the 'complex function' structure class with a variety of users and different functional groups within their structure [1]. As the most advanced health structures, hospitals have been transformed with new requirements and systems throughout history. As a result of the discussions and studies carried out in the second half of the 20th century, especially between the years 1950-1980, a wide literature on hospital designs were created and hospital structures developed as a result of technology, construction system, and inventions. The change and transformation experienced over the years have brought variations in the hospital design language.

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While language consists of a set of words with rules, architecture produces spaces that shape life with rules. Just as the language consists of a combination of canonical words, architectural designs may form space within the framework of certain rules (standards) according to function, environmental data, and topography. In order to analyze the design language of the resulting space, new spaces can be derived by analyzing the formal formation rules of the design language and producing meaningful rules with the shape grammar analysis technique. The aim of this study is to produce a rule-based model by using computational design methods to reveal the polyclinic plans of hospitals with complex functional structure types that have the same use as the shape grammar analysis technique and create shape rules and produce new plan types. The theoretical background of the study is based on the rule-based design approach. Hospital structures have a rule-based understanding in terms of both workflow, settlement and space relations. According to this work scheme, patient registers to nurse counter, waits for the polyclinic queue, examined in the proper section, the examination is directed if desired, and if not, the treatment method is given and the patient is released from the polyclinic (Figure 1).

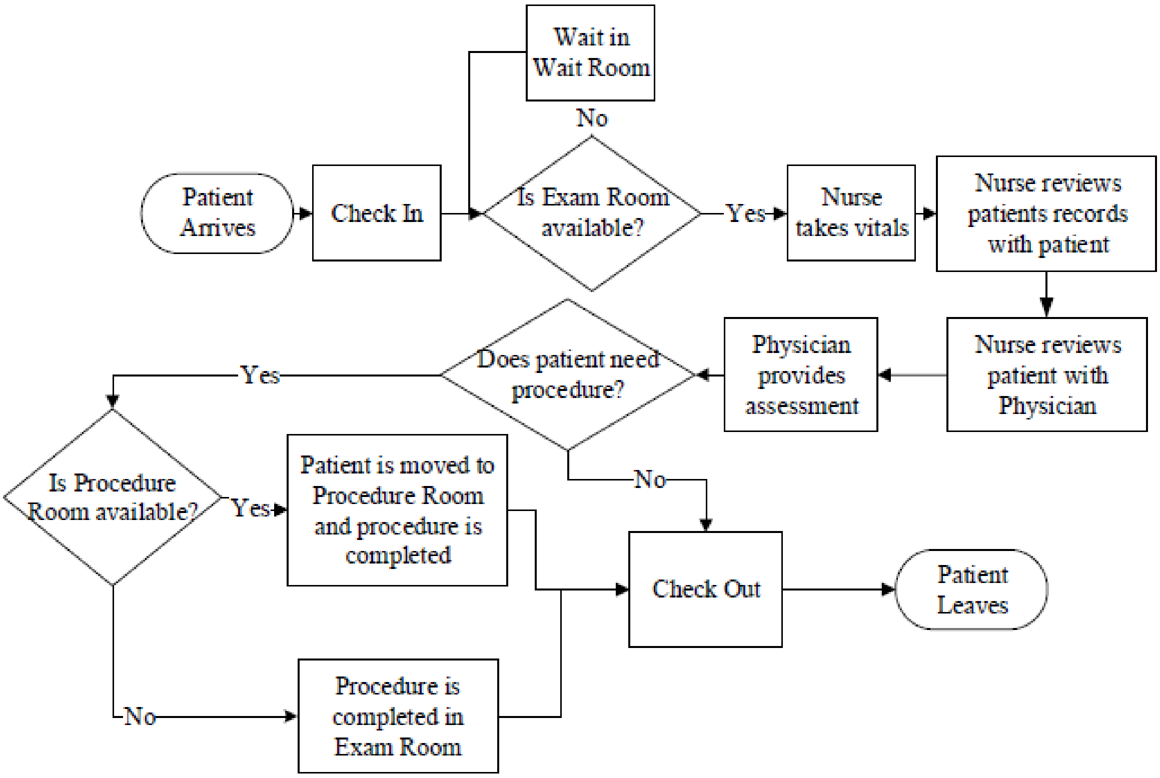
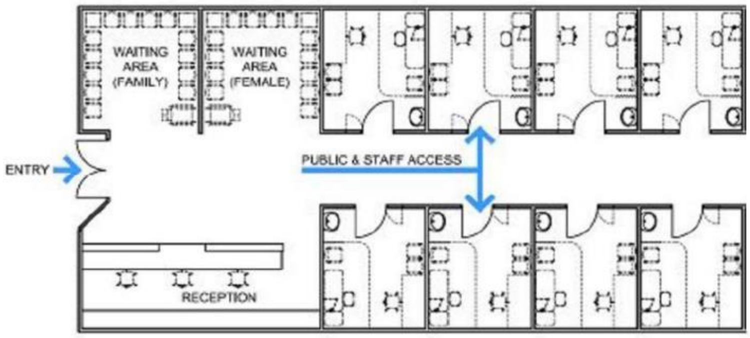


Figure 1. Hospital Polyclinic Work Flow Scheme [2]

The plan is a representation of a design in two dimensions; it can be defined as the numerical/linear expression of the practice. Hospital plan diagrams may have variety of single and double corridor types. In addition, polyclinics with different corridor types can be linked to each other and create new developed plans. According to corridor type, polyclinic layout plan has alternative of ‘U', 'T', 'H', 'I' type plan schemes.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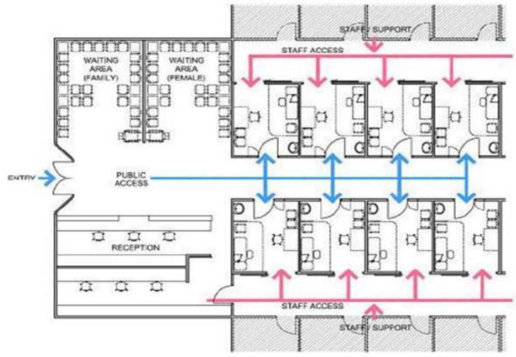
WAITING AREA (FEMALE)
ENTRY
PUBLIC & STAFF ACCESS
RECEPTION

(a)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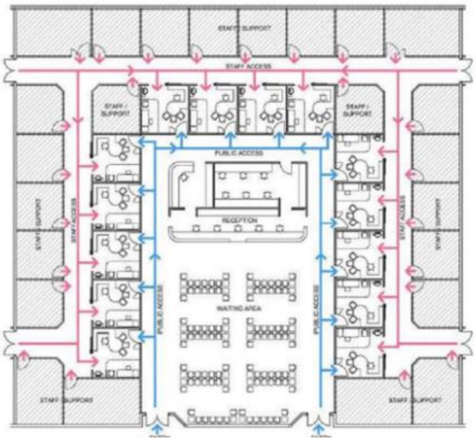

(c)


MEDICAL SUITE 1 - SPECIALIST
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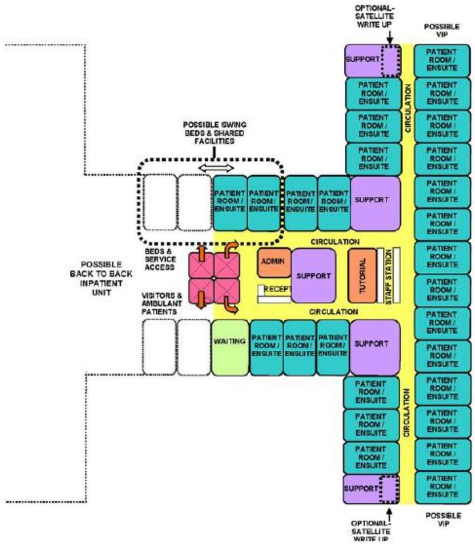

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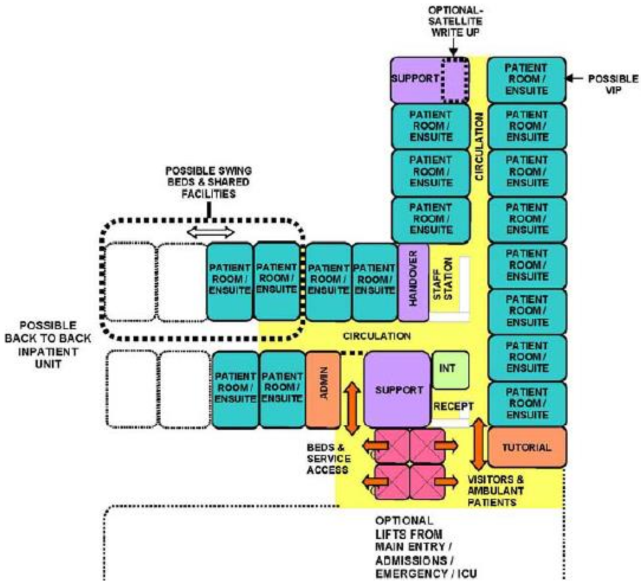
OPTIONAL-SATELLITE WRITE UP
SUPPORT
PATIENT ROOM / ENSUITE
POSSIBLE VIP
CIRCULATION
POSSIBLE SWING BEDS & SHARED FACILITIES
HANDOVER
STAFF STATION
POSSIBLE BACK TO BACK INPATIENT UNIT
ADMIN
INT
RECEPT
TUTORIAL
BEDS & SERVICE ACCESS
VISITORS & AMBULANT PATIENTS
OPTIONAL LIFTS FROM MAIN ENTRY / ADMISSIONS / EMERGENCY / ICU

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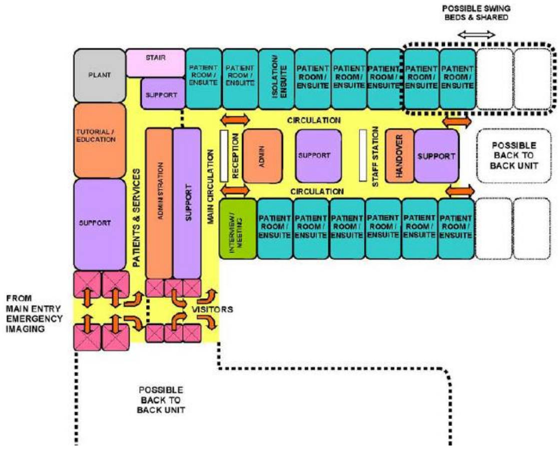


(g)

Figure 2: Hospital Outpatient Clinics Plan Schemes (a), (b), (c), (d), (e), (f), (g) [3]

1.1. Purpose

Hospitals have a dynamic structure, but at the end of the process of transforming the inputs they receive, they are among the structures where the feedback mechanism works [4]. Hospitals are defined as social systems, socio-technical systems, systems that can adapt to the environment, and open-dynamic systems. It has a social system because it interacts with the environment, and it has a socio-technical structure because the social system and technology constantly affect each other. At the same time, it has an open-dynamic structure that can adapt to the environment and has a feedback mechanism [4]. The main purpose of the study is to create a model for alternative plan types by using the productive design methods of hospitals with a dynamic structure and to develop the optimum solution proposal by evaluating the existing designs and derivatives. By considering the external patient-centered hospital polyclinics, and considering the shape grammar, genetic algorithm, and space sequencing methods an optimum solution proposal was developed in terms of two architectural programming variables: distance and visibility. The problem discussed within the scope of the article; is to create a design assistance for hospital polyclinics that defines how the units are related to each other in terms of technology, health and hospital management.

What is intended to be realized in the design technology intersection is to rationalize the design inputs, create an optimum design base through software and use this design base in model formation.

1.2. Content

Today, the design of health structures is important in the delivery of health services, which are becoming increasingly complex. At this point, it is aimed to offer a broad perspective on hospital designs, which are among the health structures of architectural design. Various studies are carried out to improve health care and to provide a comfortable environment. This study investigates the hospital design optimization by creating spaces with minimum route overlap, minimum walking distance and high visibility for polyclinic patients. In order to obtain the ideal design, accurate data were used to obtain results through various software. In this context, computational design methods were used. The study aims to create the polyclinic architectural program creation with design research techniques considering the development process and to use a design base model production with the system developed together with various hospital design standards, needs, feedback, analyses and evidence-based method. The proposed method aims to constitute a common input for a polyclinic design. The most distinctive feature of polyclinics is the repetition of spaces. Theoritically, repetitive structures are defined as well-defined [5]. The nature of polyclinic plans can give opportunity to evaluate by the shape grammar analysis and the derivation of spaces can be defined with rules. The optimization of spaces is provided with shape grammar rules and derivated with genetic algorithms. It is essential to evaluate these plan alternatives to explore the best solution with minimum walking distance with highest visibility. Space sequence method of space syntax benefits to constitute an optimum plan solution for this study. The main research problem of the study is to determine an optimum polyclinic design solution with the assistance of rule-based software programmed with shape grammar method and evaluated with spatial sequence method.

1.3. Method

In the study, a triple linear model has been used: discover shape grammar rules, derivate with genetic algorithms, evaluate alternative solutions (figure 3).

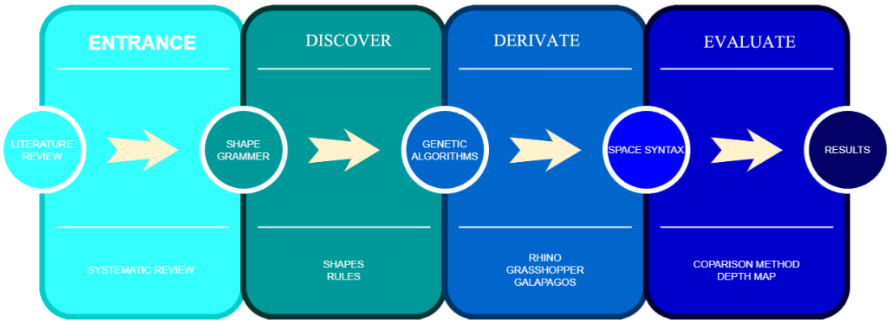


Figure 3. Method Diagram

Shape grammar, genetic algorithm and space syntax method, which are the three-stage methods specified in the study, were applied as follows: In the first phase, shape grammar rules have been discovered with the aid of rules, codes and existing designs. The dimensions of the polyclinic spaces were revealed by examining the hospital polyclinic plans within the framework of shape grammar. In this context, spatial relationships were revealed from the hospital plans examined and rule sets were established. In the seond phase, genetic algorithms were applied to polyclinic architectural program with defined shape grammar rules. All the data obtained were created by using the Grasshopper program for space production in the genetic algorithm and the model created was defined by a relationship-based optimization circuit. In the final phase, the alternative plans obtained from the shape grammar method were evaluated in terms of visibility, depth and readability to explore the best solution for minimum walking distance and visibility. In summary, shape grammar and genetic algorithm methods from rule-based designs were used in the model formation and the space sequencing method was used as an evaluation and selection method.

With the genetic algorithm, hundreds of plan alternatives from the data were created in the example of a single-aisle plan scheme. The study offers the opportunity to create separate alternatives for each plan type scheme in the following stages. The study was concluded by giving an exemplary evaluation method on how to use the space consolidation method to evaluate the visibility and depth of the obtained optimized hospital plan and existing hospital projects in the context of spatial relationships.

2. Rule-Based Design and Implementation

When rule-based design approaches are examined in the literature, different productive design techniques using shape grammar, genetic algorithms, algorithmic design, parametric design, and factor-based system approaches are examined [6], [7], [8], [9], [10], [11]. The rule-based designs that bases the method of this study are discussed below within the framework of the literature with their contribution in the process: In literature, different productive design techniques using shape grammar, genetic algorithms, algorithmic design, parametric design, factor-based system approaches are observed [6], [7], [8], [9], [10], [11]. Knight (1997) [12], classifies shape grammars into six groups: basic grammars, non-basic grammars, sequential grammars, additive grammars, deterministic grammars and unrestricted grammars. Basic grammars consist of successive sets of rules. Added rules ensure the continuity of each other. Non-basic grammars arise from steps and derivations of the previous design. In consecutive grammars, the rule is applied sequentially. It is based on the symmetrical relationship of shapes. In additive grammar, the rule set is produced by deriving the starting shape without adhering to the sequence. In deterministic grammar, the starting form is the same for all rules. Unlimited grammars, on the other hand, produce without depending on the parametric shape. Shape grammars, which can be defined mainly as a set of rules, are an analysis/analysis and reproduction technique. Although Stiny (1977)'s works [13] are among the first examples in this field, the work in which Palladio villa plans are produced [6] includes parametric shape grammar productions. It is among the first studies to be considered in terms of the analysis of an architectural design example with a shape grammar method. Algorithmic design is a design concept that expresses the production stages as a process within a rule-based system. This term has been used in 2003 for the definition of computer software that produce space and form consistent with Terzidis' architectural program building codes, typology and language within rule-based logic. In 2017, the algorithmic design was defined by Oxman [10] as the coding of clear instructions for producing digital forms (Figure 4).

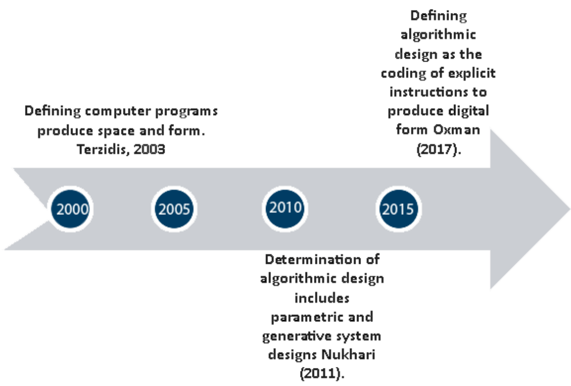


Figure 4. Algorithmic Design Time-Line

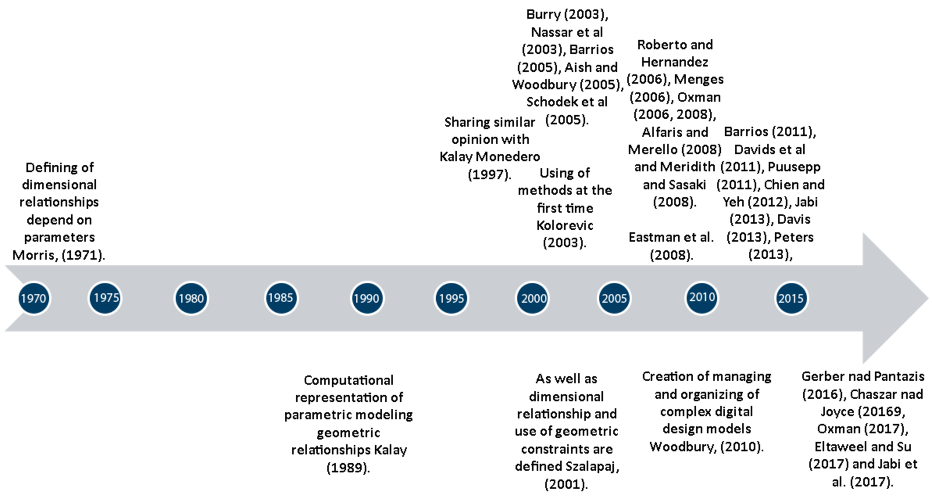


Figure 5. Parametric Design Timeline

Parametric design, is a concept that expresses the design and production stages with parameters in a rule-based system. This concept was first defined by Morris in 1971 as dimensional attachments based on parameters. Tin (1989) was expressed as a computational representation of geometric relationships, first used by Kolarevic as a method in 2003 [7]. Complex digital design models were created by Woodbury in 2010 [11] (figure 5).

2.1. Shape Grammar

In this study, the purpose is to reveal the health structure design relationship network that contains many inputs and criteria with the shape grammar technique. The shape grammar method reveals the network of relations among polyclinic units and can contribute to systematize complex health process management. In accordance with rule-based design approach, shape grammar has two types: analytical and original. Analytical grammars are sampled with traditional structures and original grammars are defined as new creations and original studies [14]. This study understands the analytical grammars within corpus of multiple hospital polyclinics and generates designs within these grammars. The allocation of generated spaces defines alternatives for design within a relationship matrix (Figure 6)

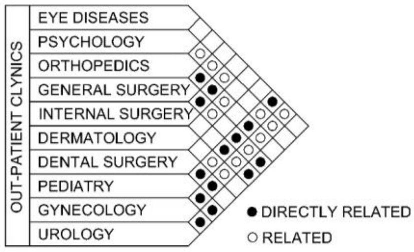


Figure 6. Polyclinic Relationship Matrix

The polyclinic units in the relationship matrix (figure 6) have a single-corridor plan scheme. Single-aisle hospital plan schemes are produced by generating rules based on the way they come together (figure 7), and within the framework of these rules, the original hospital plan scheme is given in figure 8.

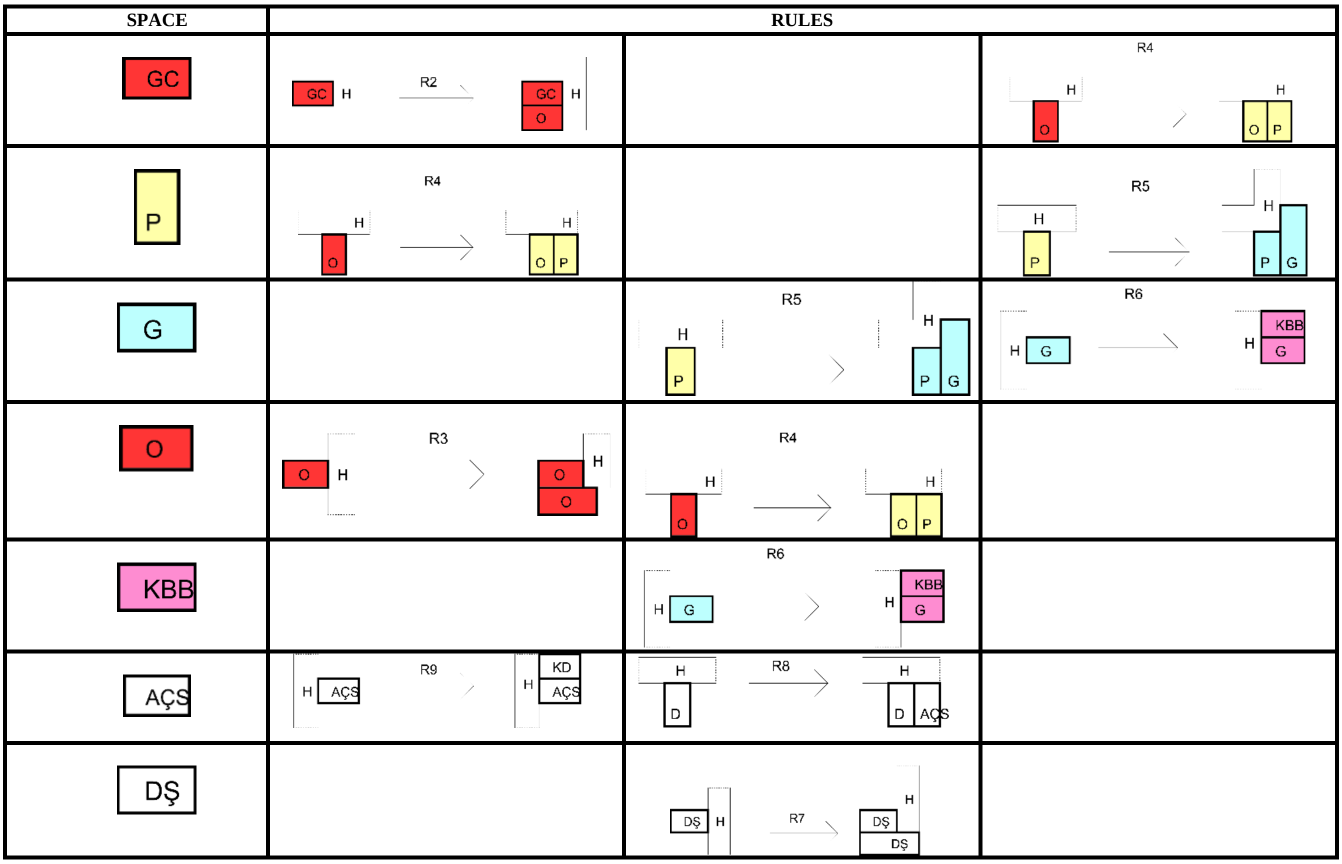


Figure 7. Rule Sets

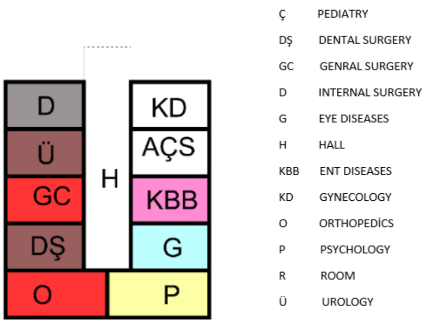


Figure 8. Polyclinic Placement with Rules.

2.2. Genetic Algorithm

Figure 9 indicates a genetic algorithm for plan productions. Accordingly; Rules were produced from the plan diagrams examined and the spatial dimensions of the polyclinics examined were interpreted within the framework of various standards and optimum space dimensions were obtained.

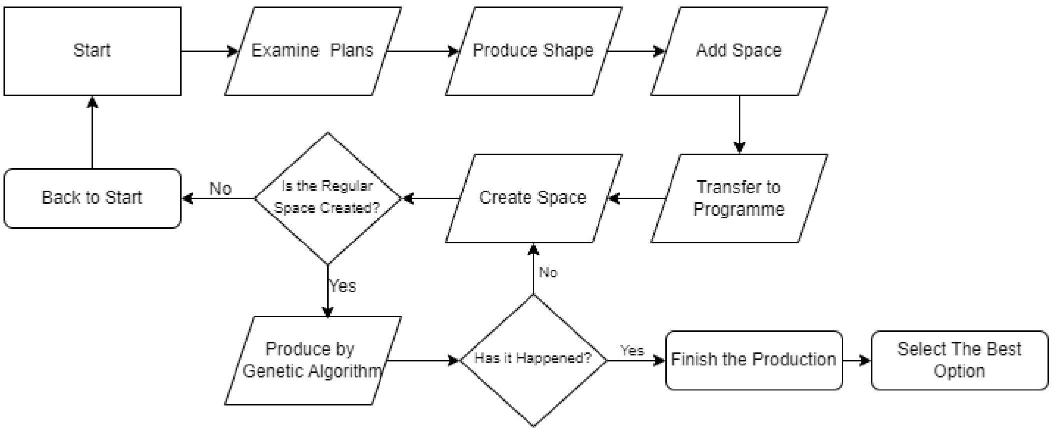


Figure 9. Production Algorithm

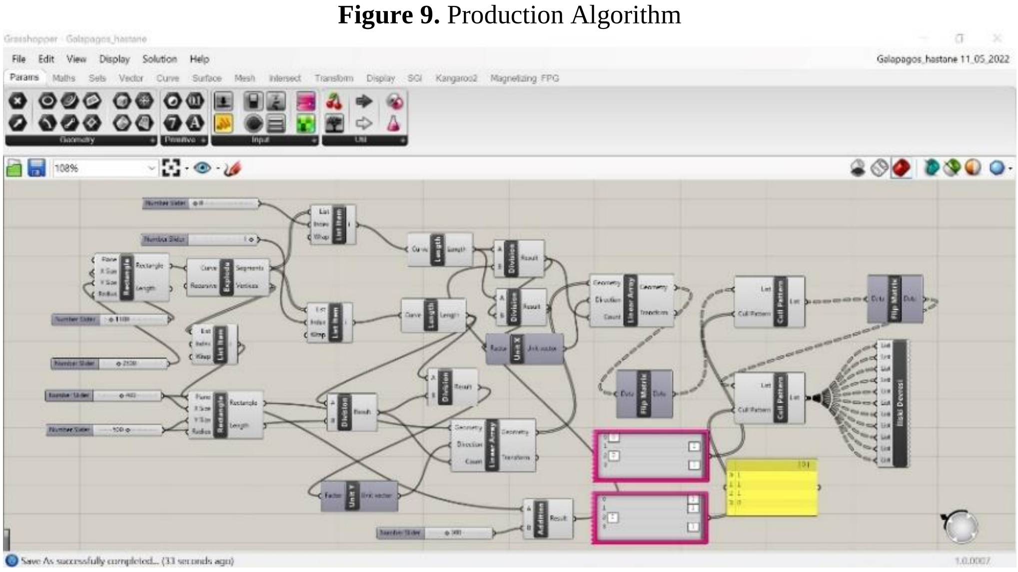


Figure 10. Model Circuit

The data on the obtained rule sets and dimensions are given in Figure 10 of the Galapagos polyclinic circuit created by entering the data that formed the basis of the grasshopper program. Here, by using the dimensions taken from different hospital plans, hospital polyclinics related to each other are grouped and it is ensured that they act within themselves and within the framework accepted as the general limit. With the produced circuit, the production of canonical space was realized. Production was completed by selecting the most appropriate plan type among the canonical optimized space productions. As a result of generation, the plan diagram in Figure 11 is given as the result product.

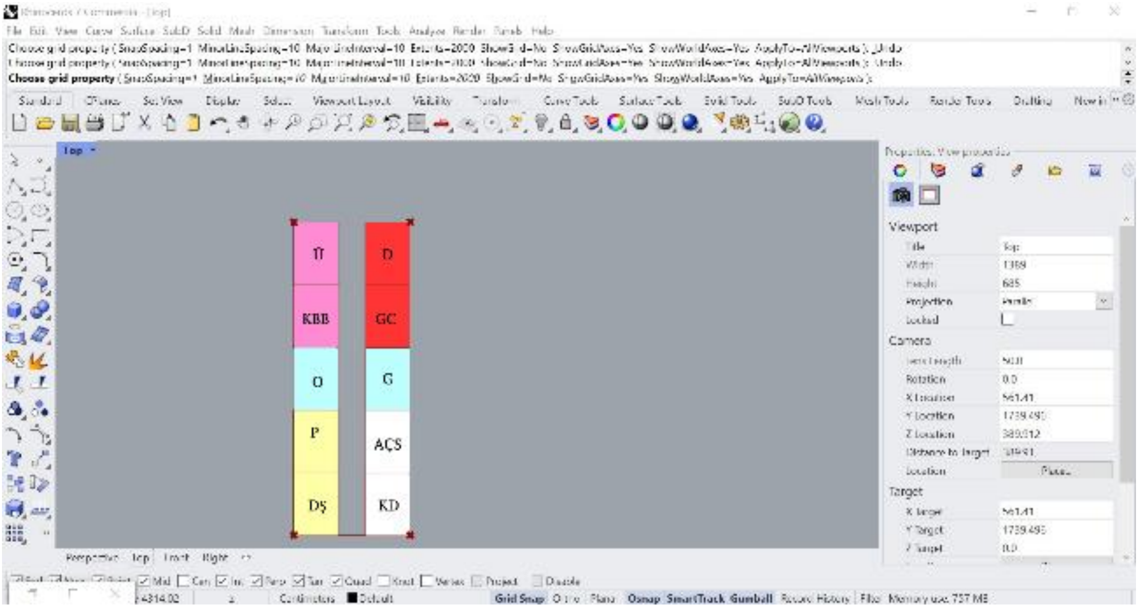


Figure 11. Selected Plan Diagram as a Result of Genetic Algorithm Generation

In Figure 12, the polyclinic unit names corresponding to the numbered spaces are given and the relations between the spaces are shown in the yellow box on the right side. For example, unit number 3 (internal medicine) is associated with unit number 4 (general surgery). The urology polyclinic, which is the number 9 unit, is associated with the internal medicine polyclinic, which is the number 3 place.

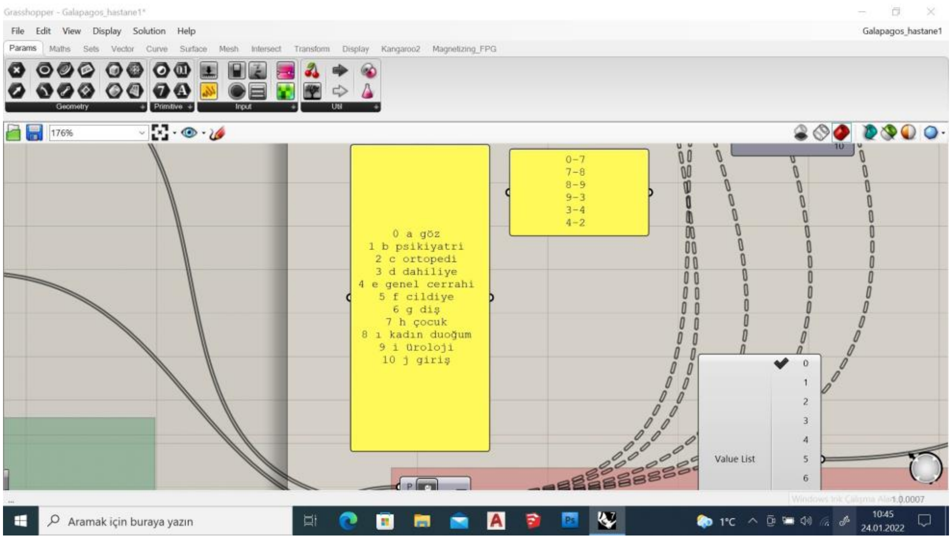


Figure 12. Polyclinic Names Assigned to Numbers and Their Relationships

In Figure 13, the circuit is made operational by entering the average dimensions on the 'X' and 'y' axis separately for the spaces defined as rectangular in the circuit. The circuit relationships created for each space relationship are given in figure 14.

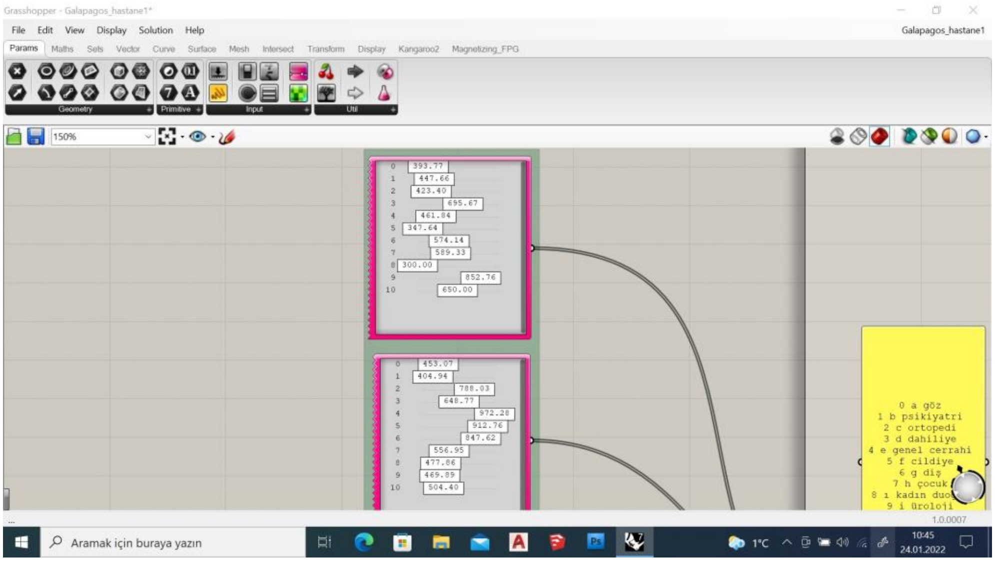


Figure 13. Polyclinic Dimension Entry

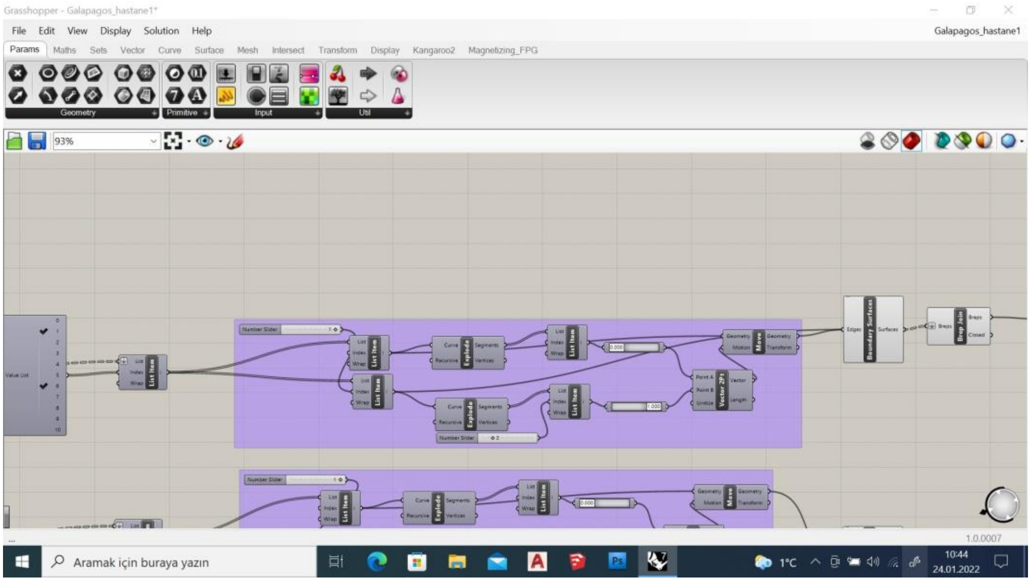


Figure 14. Relationship Circuit.

Our created circuit was enabled to produce with the Gene Pool command (figure 15), which produces a genetic algorithm. The hundreds of examples produced are shown on the screen given in Figure 16.

The spatial sequencing method was obtained from a different hospital plan. The hospital plans scheme obtained from the Ekap web-page is given as an example to define the space constellation method in this work.

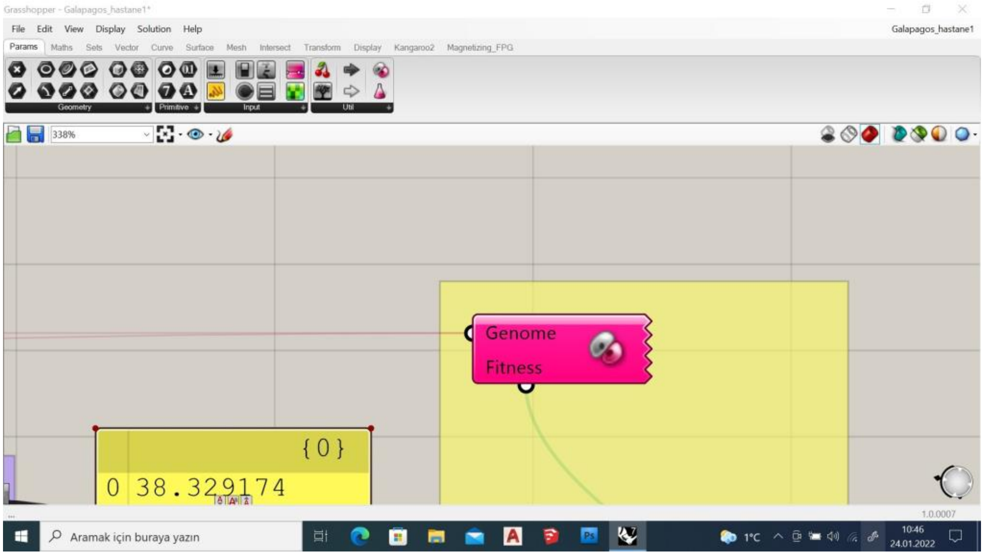


Figure 15. Genetic Algorithm Command

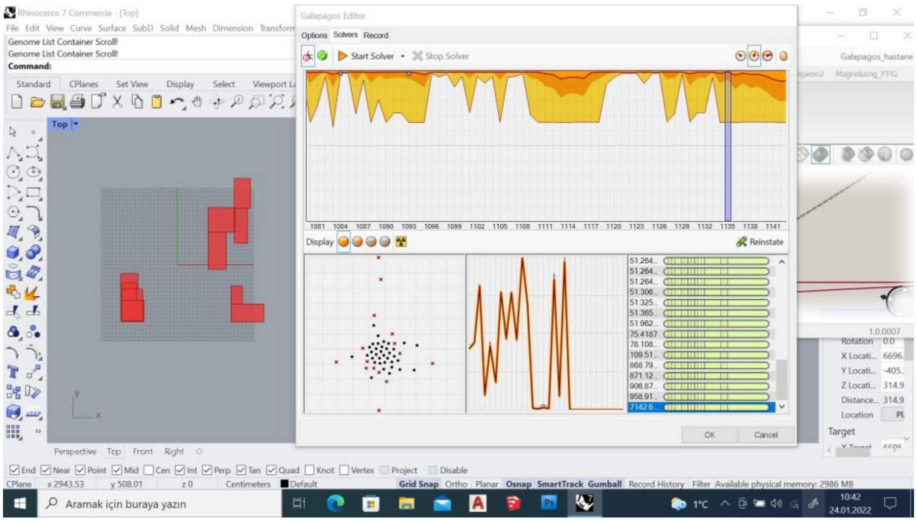


Figure 16. Genetic Algorithm Productions

2.3. Space Syntax Method

Abstract data and concrete data play a major role in the evaluation of spaces. However, it is very difficult to evaluate abstract data in an objective form. According to Hillier [15], the spatial arrangement method is a set of techniques used to explain and classify spatial formation in residential areas or structures. The aim of these techniques is primarily to examine the relationship of spatial organizations with user movements and field of view objectively. This method reveals the potential of spaces to bring users together and circulate. In this sense, the spatial constellation method, which serves to evaluate the concrete and abstract data about the space is an auxiliary tool preferred by architects to analyze spatial forms [16]. The concepts and expressions used in the analysis can be briefly defined as follows: Each space considered in the spatial constellation method expresses a knot. The relationship between spaces is expressed by edges. The relationship between the two spaces is explained in terms of neighborhood and transition.

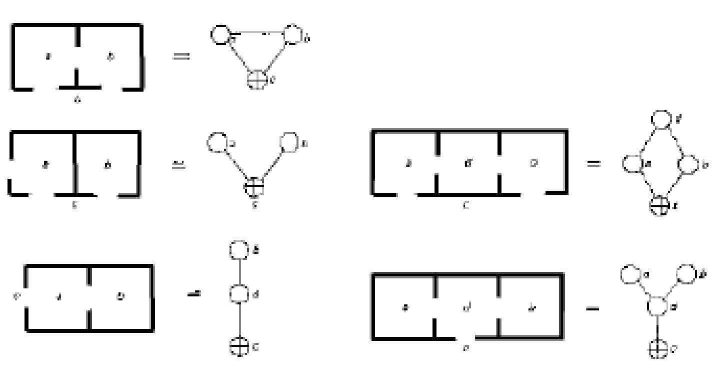


Figure 17. Transition/permeability graph (Şahin and Olğun, 2020).

In order to form the numerical expression of the syntactic structure we have considered; (1) A transition graph (neighborhood graph) (figure 17) that expresses the spatial organization of the building, (2) a depth graph (arranged transition graph) that determines the depth of each space relative to the other (figure 18). The graph method shows the relationship of the places that are transitional and connected to each other. The terms are expressed below:

- ***The graph***; is a set of points connected to each other by lines. While the point-nodes used in the method represent the spaces, the lines-edges express the transition of the connection between these spaces.

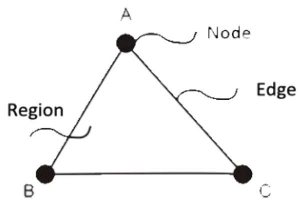


Figure 18. Example of Transition Graph Chart (Reproduced from [16]).

- ***Depth;*** is an important factor for spatial configurations. It is used in the structure to express how many steps are taken in the transition from the entrance or any space to another space (k: The total number of nodes in the graph, d: depth) (figure 19).

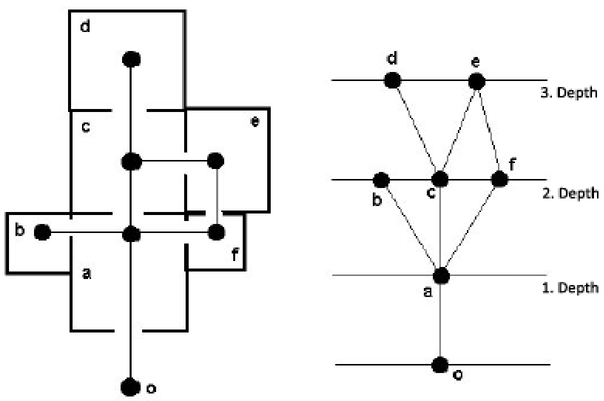


Figure 19. Transition Graph (Neighborhood Graph) and Depth Graph (Reproduced from [16]).

- **Beta Index;** Depending on the node and edge relationships of the network; numerically what kind of network the network is. The ratio of the total number of edges to the total number of nodes. If this value is β<1, the structure is wood, if it is β=1, the loop, and if it is β>1, this graph shows the complex circuit property.

- **Beta Index**; (B=E/V= Beta Index: Graph Edge/ Graph Node) (figure 20).

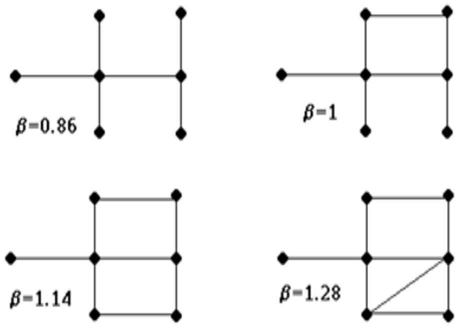
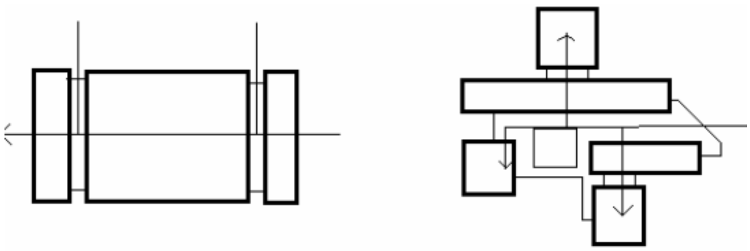


Figure 20. Beta Index [16])

- ***Gamma* Index*;*** Depending on the relationship density of the network elements; gives the "Connectivity" ratio of the network numerically. It provides data on whether the building form is compact or piecemeal. A value of 1 indicates complete connectivity, while a value of 0 indicates complete disconnection between the network elements (figure 21).

- Gama Index:

$$G = \frac{E}{(v2 - v)} / 2$$



High Low

Figure 21. Gamma index building format relationship [16]).

- ***Connectivity*:** It is a measurement of the number of neighboring places directly connected to the space. Each direct step is a local distance that measures the correct number of distances. This local criterion is the most basic knowledge of the comprehension of space. The most important point of the concept of connectedness is the reflection of the form of space based on the visual perception it creates in the mind of the person using the space. In short, it gives the relationship of each place with other spaces.

- ***Visual integration:*** Space syntax theory defines shallow spaces with high integration value as evacuation points as spaces with high visuality and permeability. These points are integrated areas where there is a lot of social interaction. On the other hand, spaces with lower social interaction are places with deep and low integration. They are numerical values that indicate that a space integrates and separates from the system.

- ***Visual mean depth:*** One of the most important relationships in the Spatial Constellation Method is the concept of depth. Depth occurs when passing through multiple intersecting spaces to get to a place. If the space to be reached has a small value in terms of changing direction, then the depth is called "shallow", and if it has a high value, it is called "deep". What is important here is that the relationship of each space with all other spaces in the system can be shown as a value. In Figure 22, the plan scheme produced as a result of shape grammar with the spatial sequencing method and the optimized plan schemes produced by using the genetic algorithm with the help of rhino/grasshopper are given comparatively:

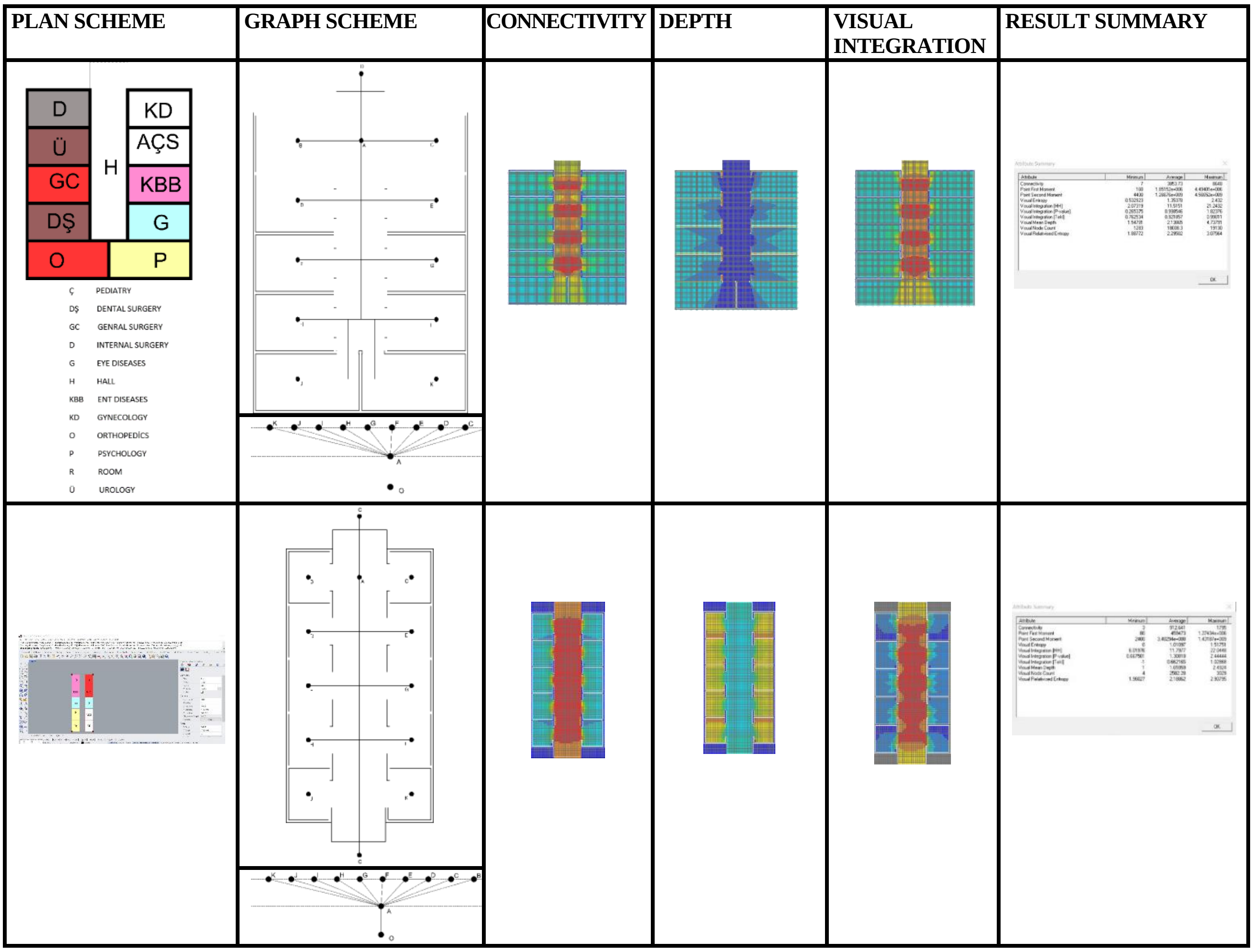


Figure 22. Analysis with Space Syntax

According to these results; in the graph chart; β<1 is the structure tree, β=1 is the loop, and β>1 is the complex circuit. The network; whether it is a tree, loop or complex circuit; defines whether the holistic form of the building is suitable for linear, cyclic or composite forms. According to the table given in Figure 22, the β values of the plan schemes produced by shape grammar and the plan diagrams produced by genetic algorithm gave the same result (β: 16/12=1.33 > 1). The structure has shown the property of complex (composite form) circuitry. It is a structure in linear form (Figure 22). According to the gamma index; A value of 1 indicates complete connectivity, while a value of 0 indicates complete disconnection between the network elements. Space syntax theory defines shallow spaces with high integration value as evacuation points as spaces with high visuality and permeability. These points are integrated areas where there is a lot of social interaction. On the other hand, spaces with lower social interaction are places with deep and low integration. The value of 0.0606 ($16/12^2$-12/2=0.0606) that we have received indicates complete disconnection (figure 22). If the space has a small value in terms of depth, then the depth is called "shallow", and if it has a high value, it is called "deep". A scheme of plans derived from the grammar of the form, which takes a high (2.138) value in the calculation of average depth; The plan scheme derived by the genetic algorithm has received a lower value (1.659) in its production and this plan scheme is shallower than the form grammatical plan scheme (Figure 22).

3. CONCLUSION

Architecture produces spaces that shape life with rules. The designs based on the original designs guide the designer in the production of buildings. In our study, the three-stage method of shape grammar, genetic algorithm and space syntax methods were applied. Firstly, hospital polyclinic plans were examined within the framework of shape grammar and polyclinic spaces were revealed with their dimensions. By obtaining the dimension and area relationship, the average space dimensions were extracted and the hospital plans examined were revealed with their spatial relations in this context and rule sets were created. Shape grammar method was carried out by following the adaptation of the space dimensions and traditional plan mentioned in Erem and Ermiyagil's study [17]. All the data obtained were used in the genetic algorithm to produce space by using the Grasshopper add-on and Galapagos module of the Rhino program and a model was defined by a circuit. This circuit is defined as a relationship-based optimization model (relation-based optimization 'Rbo'). With a genetic algorithm, hundreds of plan alternatives from the data were created in the example of a single-aisle plan scheme. In the later stages of the study, it was aimed to create separate alternatives for each plan type scheme (U, H, T, L, etc.). In this study, where canonical building design methods were used together for all these purposes, it was seen that the optimized plan schemes produced from polyclinic plan schemes were in a shallower structure than the rule-based plan schemes. These were located in the space class where social interaction was high in terms of their structure, were more efficient in terms of visibility and density and were suitable for the growing possibility of hospital polyclinics.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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