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THE ARCHITECTURAL DESIGN EDUCATION IN THE AGE OF INDUSTRY 5.0: STUDENT PROJECTS AS A RESPONSE TO THE *CHALLENGES* OF DIGITAL TOOLS AND SUSTAINABLE PRACTICES

ENDÜSTRİ 5.0 ÇAĞINDA MİMARLIK TASARIMI EĞİTİMİ: DİJİTAL ARAÇLAR VE SÜRDÜRÜLEBİLİR UYGULAMALARI ÖĞRENCİ PROJELERİYLE ELE ALMAK

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Abstract
This study explores the transition from the Fourth Industrial Revolution (Industry 4.0) to the Fifth Industrial Revolution (Industry 5.0) within the architectural design discipline. Human-centered innovation is a crucial factor for Industry 5.0, which integrates advanced technology to enhance quality of life and achieve sustainable development. The article aims to examine how architectural design is influenced by the shift between the Fourth Industrial Revolution (I4.0) and the Fifth Industrial Revolution (I5.0). The study focuses on how digital tools and smart technology can be employed in architectural design to create high-performing, eco-friendly structures while involving the end-user in the design process. Addressing the gap between theoretical frameworks and practical applications in architectural education, this study presents student projects as a foundation for discussing design proposals tailored to the new industrial era, offering an alternative method to bridge the gap between theory and practice in architectural education. Through a design studio framework, it emphasizes the role of existing technologies and sustainable design strategies in addressing contemporary challenges. Five case studies illustrate the practical application of these concepts within architectural education, showcasing how design-driven innovation promotes collaboration, research, and critical thinking. By equipping design students with the essential skills to navigate Industry 5.0, this research aligns architectural education with the evolving demands of the construction and engineering sectors, paving the way for architects to actively engage in a sustainable and technologically advanced future.

Keywords: Architectural Design Studio Education, Design-Driven Innovation, Digital Transformation, Industry 5.0, User-Centered Design.

Öz
Bu çalışma, Dördüncü Sanayi Devrimi'nden (Endüstri 4.0) Beşinci Sanayi Devrimi'ne (Endüstri 5.0) geçiş sürecini ve bu dönüşümün mimari tasarım disiplinine etkilerini derinlemesine incelemektedir. Endüstri 5.0, yaşam kalitesini artırmak ve sürdürülebilir kalkınmayı sağlamak amacıyla ileri teknolojileri entegre eden insan merkezli yenilikçiliği ön plana çıkarmaktadır. Bu makale, dijital araçlar ve akıllı teknolojilerin mimari tasarım süreçlerine dahil edilerek yüksek performanslı ve çevre dostu yapılar oluşturulmasını ve tasarım sürecine nihai kullanıcıların katılımını sağlamayı hedeflemektedir. Mimarlık eğitiminde teorik çerçeveler ile pratik uygulamalar arasındaki boşluğu ele alan bu çalışma, öğrenci projelerini yeni endüstriyel çağa yönelik tasarım önerilerini tartışmak için bir temel olarak sunarak, teori ve pratik arasındaki uçurumu kapatmak için alternatif bir yöntem önermektedir. Tasarım stüdyosu çerçevesinde, mevcut teknolojilerin ve sürdürülebilir tasarım stratejilerinin günümüzün karmaşık sorunlarına çözüm bulmadaki rolünü vurgulamaktadır. Beş örneklem aracılığıyla, bu kavramların mimarlık eğitimi bağlamındaki pratik uygulamaları sergilenmekte ve tasarım odaklı yenilikçiliğin iş birliği, araştırma ve eleştirel düşünmeyi nasıl teşvik ettiği gösterilmektedir. Bu araştırma, tasarım öğrencilerini Endüstri 5.0'ın gerektirdiği temel becerilerle donatarak, mimarlık eğitimini inşaat ve mühendislik sektörlerinin değişen talepleriyle uyumlu hale getirmekte ve mimarların sürdürülebilir ve teknolojik olarak gelişmiş bir gelecekte aktif rol almalarının önünü açmaktadır.

Anahtar Kelimeler: Mimari Tasarım Stüdyosu Eğitimi, Tasarım Temelli Yenilikçilik, Dijital Dönüşüm, Endüstri 5.0, Kullanıcı Odaklı Tasarım.

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INTRODUCTION

As the architectural field evolves with the rise of smart technologies and sustainable design practices, there is a growing need to bridge the gap between theoretical knowledge and practical application in architectural education. The objective of this paper is to establish the impact of Industry 5.0 on architectural design, specifically focusing on the implications in design studio education to augment productivity and enhance design-driven innovation. The study also examines the challenges faced by architectural design education in adapting to the rapidly changing industry requirements (Bellini, Francucci, & Manzi, 2020); (Müller & Loukissas, 2020). This paper discusses the interrelation of architectural design studio education together with the current developments of Industry 5.0. It examines the integration of advanced technologies, human-centric approaches, and ethical considerations in architectural design processes. The objective of the study is to enable the students to gain an understanding of the implications of Industry 5.0 on design capabilities, collaboration, sustainability, and innovation in the architectural field. The purpose of the study is to substantiate the role of education and the academy in the developing impact of Industry 5.0. In other words, this paper aims to demonstrate the reciprocal connection between the built environment, digital technologies together with Industry 4.0 and 5.0, and academic research and development. The originality of this study is to discuss the impact of Industry 5.0, which includes faster, smarter, and more sustainable productivity in architectural design, and therefore, this paper presents authentic student projects specifically focusing on this aim. To conclude, results are discussed through an academic perspective, which focuses on using digital technologies both for design, production, and end-use.

Literature Review

The third industrial revolution (Rifkin, 2011) is the shift from mechanical production techniques, simple electronic technology, and analog machinery to digitalization in all fields of industry. This industrial revolution also called the digital revolution, affected almost all disciplines by its impacts. It marked the beginning of the Information Age. The new era changed how we perceive and experience both the material world and immaterial connections. Relatively; following the third industrial revolution within a couple of years, the transformation of communication and production technologies, the fourth industrial revolution (Schwab, 2017) occurred, which conceptualizes rapid change to the technology of various industries, societal patterns, and processes into a fully digitalized manner by increased interconnectivity, enhanced technologies, and smarter automation. In the Industry 4.0 environment, interconnected computers, smart materials, and intelligent machines communicate with one another, interact with the environment, and eventually make decisions with minimal human involvement (Gilchrist, 2016). There is an urgent need for means to shortcut the depth of the efforts required to establish and operate the digital chain (Ramsgaard Thomsen, et al., 2020); (Židek, Pitel, Adámek, Lazorík, & Hošovský, 2020) which is currently covered by the available technologies within I4.0. There is a growing trend in architectural design and the construction industry to adopt Industry 4.0 and utilize additive manufacturing processes for building construction (Dalenogarea, Benitez, Ayala, & Frank, 2018); (Niemeläa, Shia, Shirowzhana, Sepasgozar, & Liu, 2019); (Gattulloa, Scuratib, Fiorentino, & Uva, 2019); (Ivanov, 2020); (Shet & Pereira, 2021). The I4.0 paradigm involves organizing production processes by the principles of interoperability between physical and cyber systems, decentralization, real-time data analytics, service orientation, and modularity (Liu, et al., 2022). Industry 4.0 technologies applied into AEC (Architecture-Engineering-Construction) include; but are not limited to; 3D printing and digital fabrication technologies; big data, internet of things (IoT) and sensor-based technologies, cloud computing, and other various automation systems. Also, the availability of computational and parametric design software and advanced modeling tools that embed the buildings' information into the digital model (such as Building Information Modelling) create a digital track for AEC. This development generated a more sophisticated and improved workflow, and interoperability. Therefore, Industry 4.0, characterized by its underlying digital technologies and design principles – can positively contribute to sustainable economic, environmental, and social development (Ghobakhlooab, 2020). As a matter of fact, Industry 4.0 can be seen as a matter of diffusion of digital technologies and interdisciplinary adoption. Additionally, as it is the current industrial reference and approach, it is inseparable from any discipline, which corresponds to its essential linkage with the AEC sector.

The arrival of Industry 4.0 provides links between people and objects to create an advanced productivity opportunity that ensures full digitalization of the manufacturing sector. It will also create progress in the digital working environment automatically. Development of Industry 4.0 itself can be achieved from a combination of smart construction sites, simulations, and virtualization to create more efficient construction project performance (Rahmayanti, Maulida, & Kamayana, 2019), which could be perfectly adapted as a methodology for architectural design. Scheel describes three key drivers for Industry 4.0 success: think value, not tech; think people, not tools; and set clear targets from the start (Nokia, 2021). I4.0 results as many new terms for the end user as it creates tighter interactions between human users and their mobile devices pushing towards the internet, where the human user becomes more central than ever, and where their devices become their proxies in the cyber world, in addition to acting as a fundamental tool to sense the physical world. The current Internet paradigm, which is infrastructure-centric, is not the right one to cope with such an emerging scenario with a wider range of applications. This calls for a radically new Internet paradigm, which we name the Internet of People (IoP), where humans and their devices are not seen merely as end users of applications but become active elements of the Internet (Conti, Passarella, & Das, 2017). Digitizing manufacturing and business processes and deploying smarter machines and devices may offer numerous advantages, such as manufacturing productivity, resource efficiency, and waste reduction (Tortorella & Fettermann, 2018). Thus, the current industrial revolution helped to upgrade the life quality of the end-user by offering improved design solutions with advanced technologies. With the development of industrialization in the information age, intelligent technologies have been applied to architectural design. The deep integration of new technology and architectural design not only guarantees the quality of buildings but also promotes the sustainable development of the construction industry in a far-reaching way (Zeng & Lai, 2020).

Industry 4.0 was the current paradigm in manufacturing and industrial technology. It represents the fourth industrial revolution, characterized by the integration of smart technology, automation, data exchange, and other advanced technologies in manufacturing processes. Industry 4.0 focuses on creating smart factories and supply chains that leverage technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and robotics to improve efficiency, flexibility, and productivity. As of that time, Industry 5.0 had not yet been widely recognized or adopted, and there wasn't a clearly defined set of principles for it. However, it's common for discussions about future industrial revolutions to emerge as technology advances. The transition from one industrial paradigm to another typically involves a significant leap in technological capabilities and a redefinition of how industries operate. The idea of Industry 5.0 might encompass further integration of advanced technologies, potentially focusing on areas such as:

1. Human-Machine Collaboration: A stronger emphasis on the collaboration between humans and machines, where advanced technologies like AI and robotics work in tandem with human workers. This could involve more intuitive human-machine interfaces and increased adaptability of automation systems.

2. Sustainability and Circular Economy: A shift toward more sustainable and environmentally friendly practices in manufacturing. This might involve a greater focus on recycling, reducing waste, and creating closed-loop systems in production.

3. Customization and Personalization: Increased emphasis on personalized and customized products, possibly facilitated by technologies like 3D printing and advanced manufacturing techniques. This could lead to more flexible and agile production processes.

4. Decentralized Production: A move away from centralized manufacturing towards more distributed and decentralized production models. This could involve the use of local production facilities or even on-site manufacturing through advanced technologies.

5. Advanced Connectivity: Further advancements in communication technologies, including 5G and beyond, to enable faster and more reliable connections between devices and systems in the industrial

setting.

Interpreting the shift from Industry 4.0 to the potential emergence of Industry 5.0 in the context of architectural design involves considering how advancements in technology and industrial paradigms might influence the design of spaces and structures. Industry 5.0 may call for more flexible and adaptive spaces that can easily accommodate changes in production processes. Architectural designs could integrate modular structures and smart technologies that allow for quick reconfiguration based on evolving manufacturing needs. Moreover, with a focus on human-machine collaboration, architectural designs might prioritize the creation of environments that enhance the working experience for humans. This could involve inclusive design principles, the integration of natural elements, and the use of advanced lighting and acoustics to create comfortable and productive workspaces. Additionally, since Industry 5.0 involves a move toward decentralized production, architectural designs might need to consider creating smaller-scale manufacturing facilities located closer to end-users. This could lead to the design of more compact, efficient, and sustainable industrial spaces that align with local communities.

The integration of advanced technologies like AI and IoT in Industry 5.0 may require architectural designs to incorporate intelligent building systems. This could include automated climate control, energy-efficient lighting, and smart security systems that respond to the dynamic needs of the manufacturing processes. Given the potential emphasis on sustainability and circular economy practices, architectural designs might prioritize environmentally friendly features. This could involve the use of recycled materials, energy-efficient systems, and designs that minimize environmental impact throughout the lifecycle of a facility. And lastly, since Industry 5.0 involves increased customization through technologies like 3D printing, architectural designs might include spaces specifically tailored for additive manufacturing processes. This could range from specialized rooms for large-scale 3D printers to collaborative areas for design and prototyping. The advent of Industry 4.0 has brought about significant advancements in manufacturing processes through the integration of digital technologies. However, as we move forward, there is a growing realization that the evolution of industry should not be limited to technological advancements alone. Industry 5.0, the next phase of industrial development, emphasizes the importance of human-centric approaches and the seamless collaboration between humans and machines. The transmission from Industry 4.0 to Industry 5.0 represents a fundamental shift in the way we approach industrial development. While Industry 4.0 focuses primarily on automation, connectivity, and data-driven decision-making, Industry 5.0 goes a step further by emphasizing the integration of human skills, creativity, and intuition with advanced technologies.

METHOD

Design-driven innovation can play a significant role in the integration of architectural design education with Industry 5.0. Design-driven innovation method emphasizes the importance of incorporating design thinking and user-centered approaches in the development of new products, services, and experiences (Brown, 2008); (Liedtka, 2018). When applied to architectural design education, this theory can help bridge the gap between industry demands and educational practices. Design-driven innovation also emphasizes collaboration and co-creation. In the context of architectural design education, fostering interdisciplinary collaboration among students, educators, and industry professionals becomes crucial (Demirbilek & Ekiz, 2021). By engaging students in collaborative projects with stakeholders from various fields, such as engineering, construction, and urban planning, architectural design education can provide a holistic learning experience (Dorst & Cross, 2001). This approach promotes the development of innovative solutions that align with the principles of Industry 5.0.

Design is also knowledge, as it is used to generate new meanings or forms (Jonas, 2011). As a result, design can be used as an organizational asset as well as information for competitive advantage. Through the combination of new information flows, the organization gets the ability to exploit new linkages between its activities internally and externally (Porter & Millar, 1985). Therefore, design can be perceived as applied innovation, for example; capturing the talent and resources available inside and outside the organization to create new products, environments, and new user perspectives (Gerlitz, 2015). Digitalism in architecture (Negroponte, 1995-A); (Negroponte, 1995-B) introduced a new set of digital tools for organic form-finding (Schumacher, 2008-A), led by bio-mimicry and parametric design (Schumacher, 2008-B); but not only limited only to those contexts. Consequently, the term Digital-Design Thinking emerged (Oxman, 2006-A). Due to this approach, theories and methods of digital design can no longer be conceptualized as the merging of computational tools with conventional formulations ***of design*** (Oxman, 2006-B). By extension; Advanced Architecture (Gausa, 2014) is a concept that includes the aforementioned themes, which was a trigger for bringing together digital technologies into architectural design in a socio-economically and environmentally sustainable manner. Hereby, with all those emerging tools, recent methods, and ideologies that blend architecture with digital technologies; design-driven innovation (Verganti, 2009) is an outcome to be considered as the clear connection of Industry 5.0 to disciplines that are related to design. Design thinking in architectural design education is a problem-solving approach that emphasizes empathy, iteration, and experimentation. Incorporating design thinking principles into architectural design education can equip students with the skills to tackle complex challenges in Industry 5.0 (Brown, 2008). By encouraging students to identify user needs, generate innovative ideas, and prototype solutions, design-driven innovation theory enhances their ability to create meaningful architectural designs aligned with industry requirements. Therefore, the design-driven innovation method emphasizes the significance of research and innovation ecosystems in driving creative problem solving. Integrating design research methodologies into architectural design education allows students to conduct empirical studies, gather user insights, and apply evidence-based design strategies (Razzouk & Shute, 2012). Furthermore, connecting educational institutions with industry partners and research centers fosters a dynamic innovation ecosystem, enabling the exchange of knowledge, resources, and best practices. Such collaboration strengthens the relevance of architectural design education to the rapidly changing needs of Industry 5.0. Moreover, user-centered design, a key aspect of design-driven innovation, emphasizes the importance of understanding user behaviors, preferences, and needs. In the context of architectural design education, integrating user-centered design principles can help students develop a deep understanding of how people interact with built environments (Norman, 2013). This understanding enables students to create designs that are not only technologically advanced but also enhance user experiences, addressing the evolving needs of Industry 5.0.

Fort his research, the principles of design-driven innovation, user-centered design, and digital design thinking are implemented in a one-semester architectural design studio course to bridge theoretical knowledge with practical application. Throughout the semester, students engage in project-based learning activities that incorporate advanced digital tools, collaborative methodologies, and interdisciplinary approaches. The course emphasizes integrating smart technologies and sustainability principles into architectural design, aligning with the demands of Industry 5.0. Students are encouraged to apply digital design-thinking by identifying real-world user needs, prototyping innovative solutions, and iterating their designs based on feedback from educators, peers, and industry stakeholders. Additionally, empirical research methods, such as user studies and performance simulations, are integrated into the studio projects to develop evidence-based design strategies. This pedagogical approach not only equips students with the technical and creative skills needed for Industry 5.0 but also fosters collaboration and critical thinking, enabling them to propose designs that address both technological and human-centric challenges in the built environment.

DESIGN STUDIO OUTCOMES: SELECTED WORKS

In this section, the project proposals derived from the 4th year (undergraduate) interior architectural design studio, which specifically focused on applying the principles of the I5.0 to architectural design production and application. The projects had research and development stages during one academic semester. Students were encouraged to pursue interdisciplinary investigations during the initial stages, which are followed by testing the preliminary ideas and interests. The conceptual design is developed by digital creation techniques and methods. Lastly, the theories are implied through a holistic design proposal, which includes industrial and digital methods, techniques, and technologies. This studio encourages the learner to integrate human-centric approaches and consider ethical considerations and social implications in architectural design projects (Brown & Wyatt, 2010) to bridge architectural design proposals with I5.0. Also, it encourages the student to apply challenge-based learning methodologies to foster critical thinking, problem-solving skills, and creativity (Larmer, Mergendoller, & Boss, 2015); (Vogel, Koomullil, & Schäfer, 2016). Relatively, this learning method is a top-down approach, which explains comprehensively this learning method, which triggers design-driven innovation together with digital-design thinking in AEC production practices (Birgonul & Carrasco, 2021). To align with the contemporary necessities of the AEC industry, the academy should train the new generation of students appertaining to those concerns. Thereby, this learning approach implies Industry 5.0 as a complementary context to the architectural design studio which emphasizes the importance of digital technologies and therefore design-driven innovation as a consequence.

Architects have to be conscientious and responsible for sustainable development. I5.0 has a great impact on creating projects to achieve better efficiency for sustainability (which includes conservation of natural resources, energy usage, and conscious consumption). With this reference, our design studio approach assisted the students with the conscience of current digital technology availabilities. Moreover, blending digital technologies into architectural and construction discipline triggered design-driven innovation (Barron, 2018); (Sarawgi, Sharma, Sarawgi, & Gupta, 2020) and enhanced possibilities related to digital modeling, parametric, and organic forms—from finding improvements—are discussed. Therefore, the outcomes of the design proposals have resulted as advanced examples when compared to other design studio outcomes that follow traditional methods and approaches. Additionally, I5.0 offers economic and easy access to sensor technologies; thus, the implication of data sensing and computer interaction involves the Internet of Things context to the projects. The impact creates smarter and more responsive architecture examples by proposing living systems, augmented user experience, and data-driven design. Consequently, the student works aim to reach the phenomenon of 'architecture as a living system' (Ratti & Claudel, 2016); (Davis, 2021) or 'an organism'. As another consequence, the impact of I5.0 in architectural design enables a sustainable learning cycle by creating advanced and interdisciplinary links.

Project I: 'Mitigation Lab'

It is a clear fact that the production and consumption systems that dominated the 20th and 21st centuries have caused many crises, including climate change. This crisis inevitably changes our environment and, therefore our way of life. Adaptability to the crisis is crucial for our physical environment and the way we design it. One of the most important examples of this crisis in our environment is undoubtedly found in one of the mega-cities of the world: Istanbul. The Golden Horn, which was full of pavilions, palaces, and green areas in the past, is a region where the ecosystem is destroyed due to the pollution caused by industrialization and overpopulation. 'Mitigation Lab' is a laboratory and research center located in the Golden Horn of Istanbul; aiming to establish self-sustaining, high-quality built environments and societies that will be in harmony with nature. The main purpose of the Lab is to collect data, transform data into information, and create new production and consumption systems using this information. By using nature, 'Mitigation Lab' transforms and purifies the Marmara Sea water and other waterways connecting to it, and produces new materials for the built environment. The project is described as a hub for the production back to the city: 'A Systematic Change for Reunion with Nature'. Apart from changing the production-consumption systems and the production of new materials, another important aim of the lab is changing human behaviors. While the new system in the lab is prepared in detail from the smallest scale (material) to the largest scale (city), this design scenario puts humans at its center. The lab operates with a biological production and circular economy system where materials are grown within the facilities of the proposed establishment, and production-consumption activities take place in a completely closed loop. The ability of biological production and materials to adapt to crises and the new normal is used to build the future of our society. The Lab doesn't consider 'waste' as something of no value. Instead, it sees waste as a source for new processes. It conveys this awareness to its users. At the Lab, the input of one production may result from the output of another production and consumption, and in this way, those activities are linked through a closed value loop (see Figure 1).

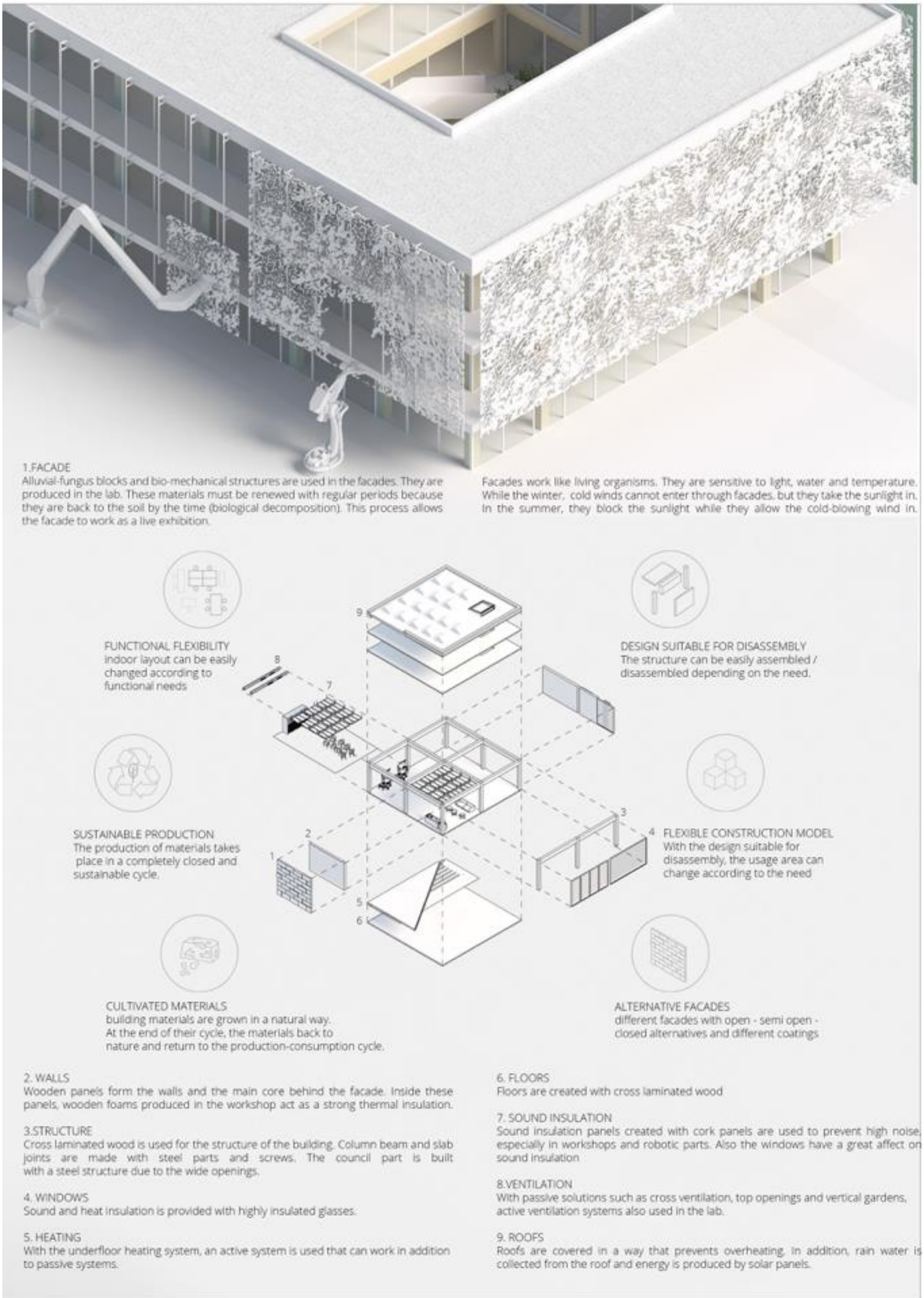


Figure 1. 'Mitigation Lab' Design Mechanism, Functions and Material Studies.

The project focuses on two main organic materials to reproduce building materials. Those materials are the synthetic grasses and the alluvial blocks (see Figure 1). Synthetic Grasses To improve the aquatic ecosystem in the region, synthetic seagrass meadows are produced by 3D printers, which disappear over time due to pollution. The e-coli bacteria were added to the printed grass-like material. These meadows produce the food needed for the habitat as well as a type of fuel that can be used for energy. Within the design scenario, water is purified by natural elements that are placed by the laboratorians. The natural cleanse is done by aquatic creatures such as mussels, oysters, and pina-nobilis (a special type of mussel used in the purification and cleaning of water from mud). Moreover, Alluvial Block and Soil Alluvium-mud collected by the local municipality from the ground of the Golden Horn is delivered to the Lab after being dewatered by the municipality. After processing in cultivation and water laboratories, agricultural soil and sediment blocks are produced. Lastly, various materials produced in the experimental laboratories produce massive amounts of waste. The waste materials of the experimental lab are used as recycled materials for the built environment that are produced in the Lab. The most important of these are the experimental facade materials printed by robots. This complex composite composition is formed by the combination of chitin, pectin, and synthesis proteins. These materials are first applied to the façade of the Lab functions are examined and necessary improvements are made after testing them at the 'Mitigation Lab' for their further use (see Figure 2).

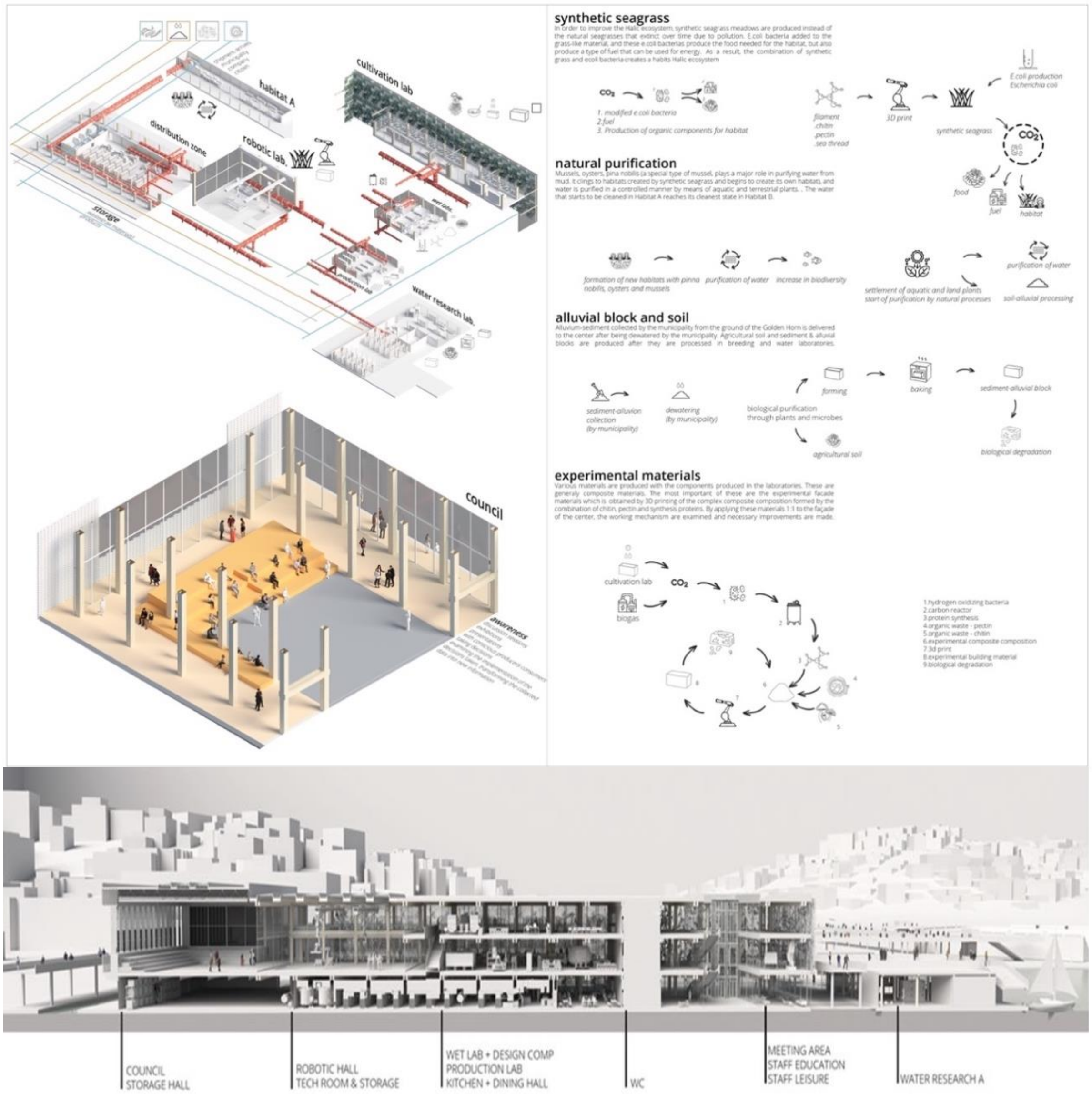
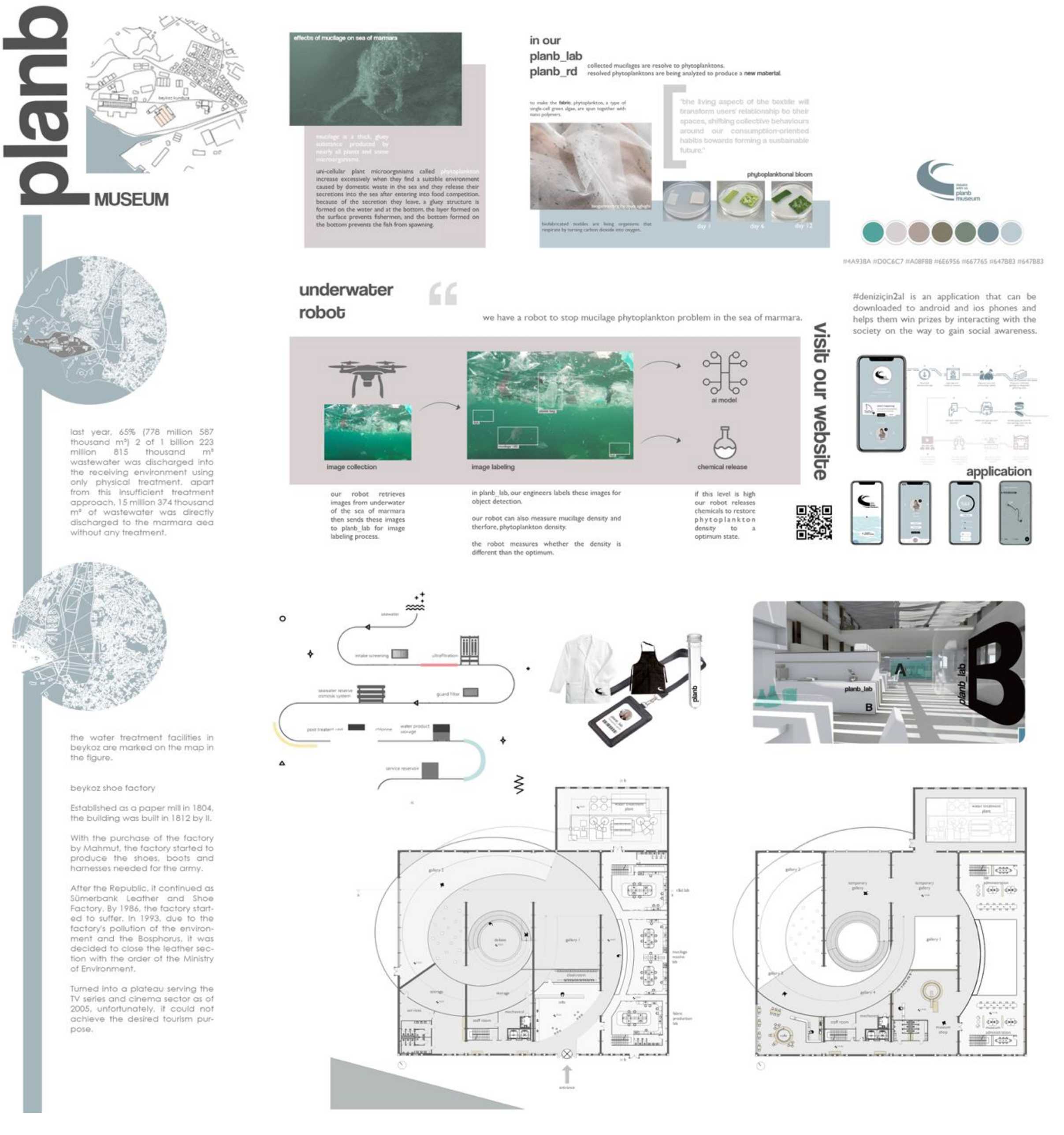


Figure 2. 'Mitigation Lab' Design and Facilities

As a result of this project, digital technologies, and recent fabrication methods are gathered in a research & development hub. The main objective of this project proposal is to create a sustainable solution to the environmental crises experienced in Istanbul. The project proposes a symbiotic usage scenario that examines the system with all its components and makes them coexist with nature as a whole. Industry 5.0 by its facilities enabled this project to get closer to the possibilities of the realm. The originality of this work is to bring together nature with digital production techniques to create a sustainable environment, which is a proper example of an outcome of Industry 5.0. The 'Mitigation Lab Project is an example of the implication of Industry 5.0 to architectural design to engage architectural design with the digital industry. Proposed outcomes clearly show that utilizing interdisciplinary production techniques could provide sustainable socio-economic and environmental results for both local and global cycles.

Project II: 'Planb_Muesum'

The 'planb_museum' project is an underwater museum, that raises awareness in society about the water pollution that creates the mucilage problem on the Beykoz, and Istanbul coasts of the Marmara Sea while conducting underwater and recycled materials research and development in its laboratory. On the other hand, it provides a museum space for people with a debate area and digital experience



galleries augmented by virtual reality (see Figure 3). The project aims to detect and collect the mucilage in the Sea of Marmara, to produce a living material by recycling the collected mucilage, and to raise awareness of the society collectively so that such a problem will not be encountered again. The technologies used were designed underwater robots that retrieve images from underwater and then send these images to a laboratory for the image labeling process. In the laboratory, engineers label these images for object detection. Underwater robots can also measure mucilage density and therefore, phytoplankton density. If the level of density is high, the robot releases chemicals to restore phytoplankton density to an optimum state. Other than that, it collects mucilage and brings it to a laboratory for a resolving process to create a new material. Resolved phytoplanktons are combined with nano-polymers to produce the living fabric that turns carbon dioxide into oxygen.

The 'planb_museum' project proposal includes such as sand arresters, preliminary and final sedimentation tanks, and sludge settling ponds. All the recycling processes are planned to be maintained by data-driven control mechanisms. In addition, to include society in this system, a mobile application was developed. With this application, people gain coins by collecting garbage around the city and leaving them in containers located in certain places in the city for the recycling process. With the coins they earn, they can get tickets to the galas, movies, and museum events held in the region. Moreover, with this app, the research & development done in the lab and the water cleanse process can be transparently tracked by the public. Also, the community receives information about the news and events that are held in the facility by this app. The outcomes of this project prove that if awareness is to be created, people should be included in the process as well as applying technology. The connection between design-driven innovation is not only cleaning the Marmara Sea by collecting mucilage but also using it to create a new living fabric that can be used in different areas (decorative, in fashion, as an installation, etc.). Moreover, within the scope of this project, not only digital innovations in architectural design but also mechanical engineering and recycling methods are studied and discussed.

This project is an architectural example of Industry 5.0 regarding the Internet of Things (IoT), artificial intelligence (AI), virtual reality (VR), and machine learning. The robots that will make the necessary intervention on the coasts of Beykoz, where mucilage can reform, are part of the production process, and the fabric produced in the laboratory is part of the museum. After production, the produced material takes place as an architectural element in the museum. It turns carbon dioxide into oxygen and also appears as material to be used in built environment or as art installations. In addition, in the museum, with the help of projectors, big screens, and underwater robots, images, sounds, and videos from underwater of the Marmara Sea are projected into space to give people the feeling of being underwater. As a digital implication, this project proposes data visualization methods in public gathering areas, where the process of recycling and real-time betterment of social and environmental issues are screened.

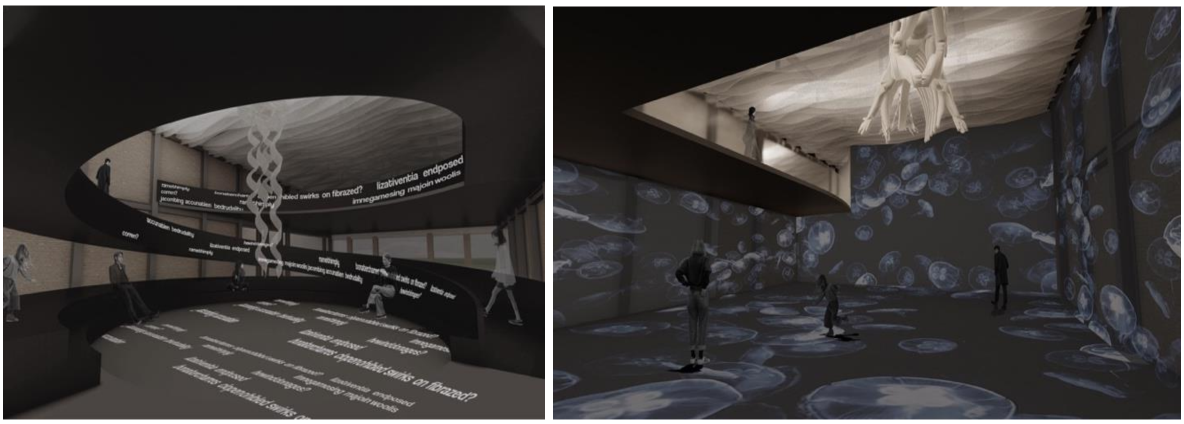


Figure 3. 'planb_museum' Design Scenario and Facility.

Project III: 'Bankoboyu'

This project proposal is located in Alsancak/Kordonboyu, to contribute to the activities of the Izmir Street Economy Branch Directorate on the subject of sustainable cities and societies. The project is entitled 'Bankoboyu', and it is compatible with the local culture and is a project that reveals a local context with İzmir. This project is an added value for the city and was determined by the people of İzmir through conducting an online survey. The problem this project has identified is that the conflict experienced by tradesmen and mobile artisans and the problems that mobile artisans experience with the municipal police are sociologically damaging to urban memory. The local producers and mobile artisans who have added cultural value to the city throughout history are gradually disappearing. With this project, by preventing the loss of local food, the materials required for the production of this local food are supplied by the artisans in the region, prepared by the artisans, and sold by the artisans, mobile artisans, and mobile tradesmen to balance production and the conception cycle. The production and supply chain of the feedstocks are controlled and tracked with digital methods. Local agriculture and husbandry are empowered by digital technology as well within the design scenario.

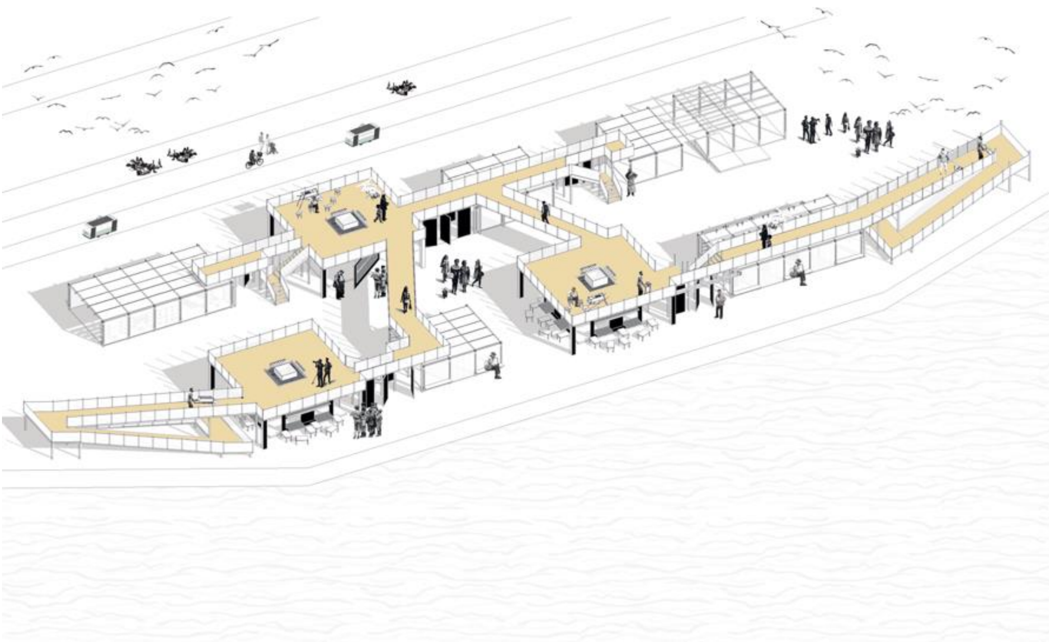


Figure 4. 'Bankoboyu' Project Proposal

The most important part of the project is that the designed urban kitchen structure can operate in different parts of the city by having fast, easy installation and assembly, increasing the vitality, and having an architectural touch that will minimize the footprint in the region. It was aimed to provide wide employment by designing the project as two layers of preparation and cooking units, and by connecting them with the upper-level viewing terrace, both the connection between the two layers was ensured, and the public was provided with the opportunity for social experience in the public space by creating collective spaces on the viewing terrace (see Figure 4). The 'Bankoboyu' project influences the city's production-consumption cycle sustainably by including artisans and mobile artisans and developing informational awareness in the community. The digital newspaper 'Artisan's Miracle' is an informative interface to establish a relationship with the subjects and the system (see Figure 5). The newspaper works as a way to reach the artisans and mobile artisans to involve them in the system. A digital application has been designed to meet and inform the user. Specific urban maps are included in this interface and nodal points are marked. These urban nodes are station points to reach mobile artisans.

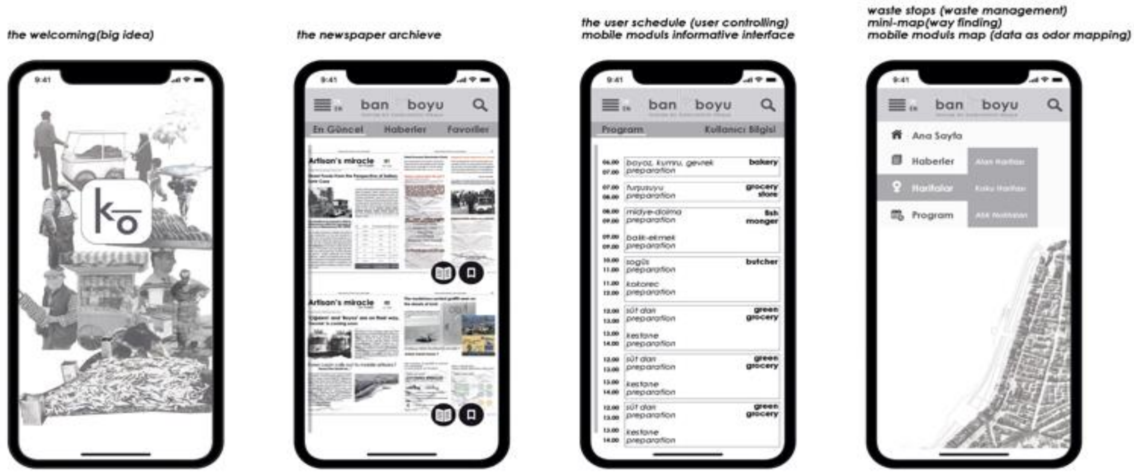


Figure 5. 'Bankoboyu'- 'Artisan's Miracle' Digital Newspaper

The ventilation and smelling problem of the designed cooking units was solved by cleaning the odor and waste gases that emerged during cooking and returning them to the space ventilation. This recycling story turns into a visual installation where the smoke movement can be experienced with the transparent pipelines designed within the system (see Figure 6). Biofiltration and the Joule-Thomson effect are the two essential components of this recycling system. Biofiltration controls air pollution and biologically reduces odors and other volatile air pollutants contained in the exhaust air stream by microorganisms. On the other hand, Joule-Thomson explains that as the pressure of the gas increases, the temperature increases as well (Zemansky, 1968); (Kittel & Kroemer , 1980); (de Waele, 2017); (Schroeder, 2000). In this project, the waste gas is reused as an experiential factor in design with the help of basic physics and mechanical solutions. This system is an example of both the implication of digital technologies and I5.0 to architecture together with the responsive architecture concept applied thanks to digital infrastructures.

Figure 6. 'Bankoboyu' Pipe System, Biofiltration, Smoke and Gas Recycle.

The form-finding situations of the units are designed by considering the product requirements to be sold and feeding on the traditional one. It has been foreseen that certain organic wastes may arise as a result of the products sold. To reintroduce this to the system; compost volumes that are called 'urban drawers' have been created (see Figure 7). While vegetables and fruits are converted into organic fertilizers; meat and fish products become a source of food for street animals. The smell, temperature, and moist, earth-quality compost values are tracked by sensors that are embedded in those drawers.

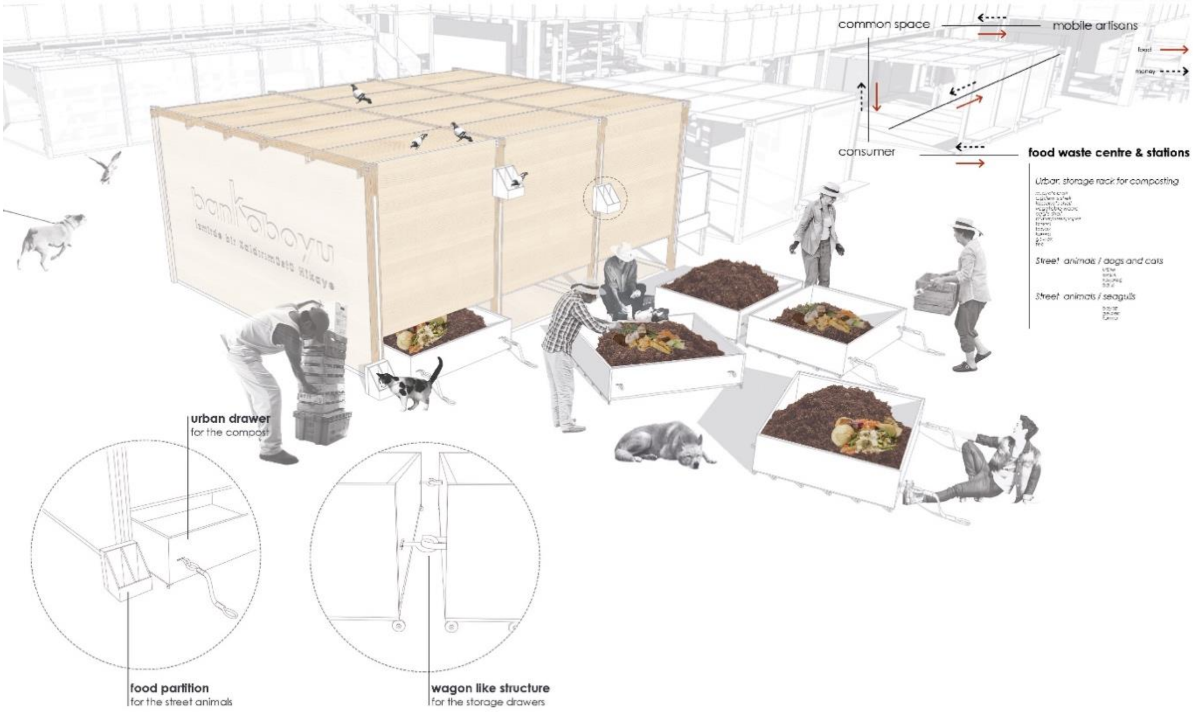


Figure 7. ‘Bankoboyu’ urban drawers

Lastly, the service corridors created between the designed units are surrounded by movable panels and protect the relationship between the city and the sea. These panels were conceived as an urban design interface for the city's street artists. In other words, it is an urban canvas and this design element also acts as a collective ‘urban memory’ piece of the project. The urban canvas is produced manually and eclectically, and on the other hand, it is documented and shared digitally by social media channels. The sales part, on the other hand, is to be sold by the mobile as well as by artisans, which will both maintain the mobility of the region by staying true to the texture of the street foods and act together by benefiting each other instead of competing with the artisans by removing the mobile from the excluded position in the production-consumption balance, which is also tracked by a digital infrastructure.The public building is developed as a smart structure with embedded digital technologies. The project has various added values, such as being interdisciplinary, multi-scalar, and being developed both for social and industrial benefit. The socio-economic concerns are investigated by digital data collection methods and design solutions are approached by a collective technique. The product design scale of the project is developed by experiential techniques, and they are all modeled and tested by digital design software. Some products and urban furniture and planned to be fabricated by digital fabrication techniques. The community can access the project from digital platforms; as well as track its data. Also; project process and development are documented and published in digital means and channels. The originality of this work is bilateral. One of them is the social outcome that addresses sustainable local commerce and the local community; on the other side, the unique approach by the usage of digital industries for the design, construction, maintenance, and production.

Project IV: 'Aqua Verde'

The building chosen for the project is ‘Paşalimanı Flour Factory’ which is located in the Üsküdar district on the coastline. The factory has not been operated since the 1940s. Today, due to the collapsed roofs, the building only has main walls, completely open to external influences. The project is developed as an adaptive reuse proposal, as it is a public bath and wellness center (see Figure 8). Besides acting as a public bath and therapy center it provides clean water, free food, new job opportunities, raising awareness for the current water sacristy and the right water consumption methods. The project aims to solve local district problems and to achieve some of the UN Sustainable Development Goals (UNPF, 2015) using industrial and innovative technologies. This design answers the clean water and sanitation goal by providing clean water from the algae water purification system.

It also aims to provide job opportunities for the poor neighborhoods in the district and also by providing free vegan algae powder for food. It also answers the good health and well-being goal by providing public bath and therapy centers. Finally, it answers the responsible consumption and production goal by raising awareness for the current water scarcity in Istanbul and responsible water consumption methods. The project offers a self-sustaining production and recycling system (see Figure 8). The technologies used were algae purification technology.

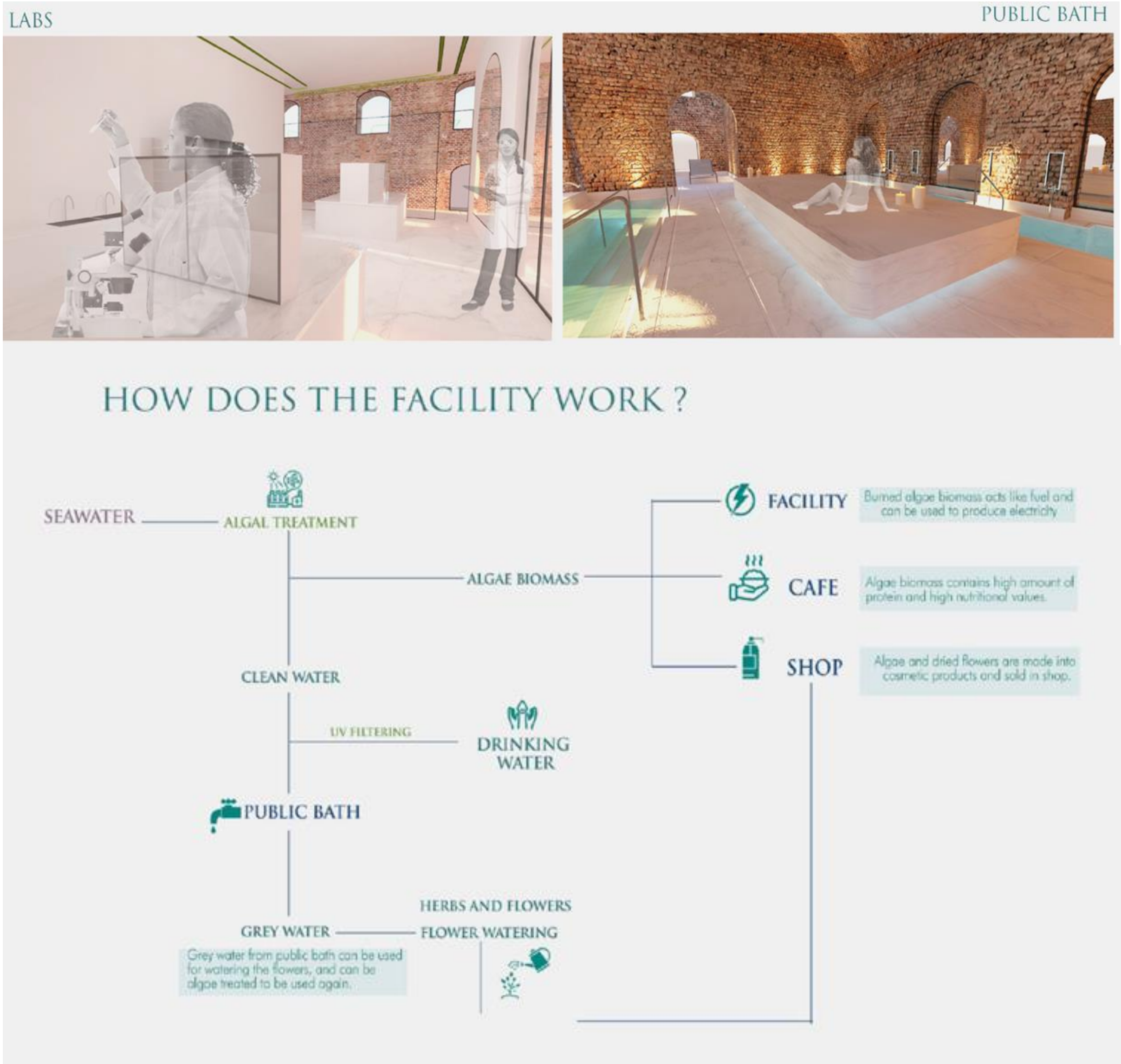


Figure 8. 'Aqua Verde' Facility Diagram

This purification method consists of algae piping infrastructure, algal tanks, algae procession, algae energy production, and algae faucet systems. The algae tanks distribute the algae water through the pipes that circulate the whole building. This algae pipe generates more algae as it circulates. It also acts as a wayfinding method and an interior aesthetic element. After seven days of circulation inside of the building, the algae water is collected and put through the EWS Algae A60 (Origin Oil, 2013). This machine separates the algae from the water. The algae are then harvested through the algae harvester and dried using the spray drying machine. The dried biomass is used in several things. It can be compressed with oil press machines and turned into algae oil. The algae oil is further processed with transesterification reactors forming biodiesel and producing energy. Algae have the natural look of the green in the building, through the transparent pipes giving a relaxing feeling through the facility.

Also; during the algae night cycle with the right conditions and the right ingredients, the algae will naturally glow which gives an extraordinary feeling inside the facility. Unlike soil-based plants which use 90% of their energy to support their structure, algae can use 100% to produce oxygen. 15 liters of algae solution can produce the same amount of oxygen as two young trees. Under the right conditions, algae can make a lot of oil that can be converted into biofuels.

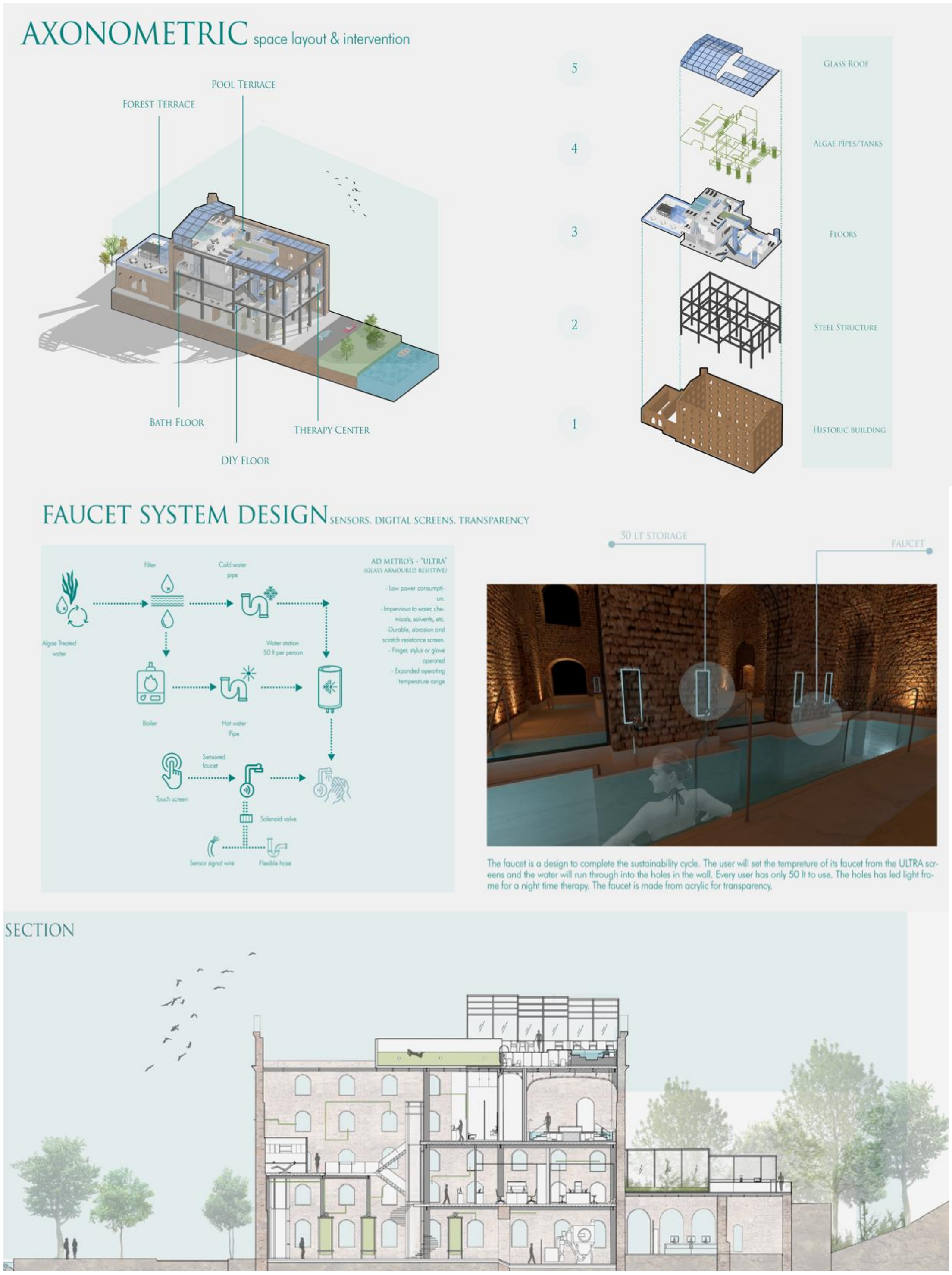


Figure 10. 'Aqua Verde' Design and Facilities

Another unprecendent benefit of growing algae in wastewater is that the organisms clean the dirty water. In the spa of the facility, algae-based treatments are used. The products that are produced in the labs are cosmetic products that are all algae-derived. Another way of using the biomass that is reproduced in this facility is in food. The dried spirulina biomass contains all the essential amino acids and proteins for human being. It can be used as a nutrient and could be added to salads or soups. This product is served in the 'Aqua Verde' café. The remaining collected water from the pipes is Algae-cleaned water. This clean water is converted into drinking water using a UV filtering system, or it can be used through the algae faucet system. This faucet system is designed to bring a specific amount of water for every user in the bath section. Some of the filtered water is carried to the boiler. The remaining water is carried directly to faucet tanks and combined with the boiled water in the bath section. Every tank holds 50 Liters which is just enough to take a shower without wasting any water. The tanks are visible in the bath section raising awareness for users. Once the users approach the censored faucets the water starts flowing giving the unique experience. The recycling and water purification system is controlled and maintained digitally.

The outcomes of this project prove that using Algae as a natural element in the industrial world can be a solution to several nowadays problems. Algae is a promising bio-material that could be used as a recreative element to address various ecologic and socio-economic concerns. The 'Aqua Verde' Project is an example of the implication of Industry 5.0 to architectural design to bring together various existing technologies that create design-driven innovation. Using a bio-material in an architectural context is only possible with the current technologies and advanced machinery that are available thanks to I5.0. The biology and chemistry labs are equipped with high-tech computers and equipment for algae research. Moreover, the digital data tracking methods, the internet of things, and data visualization techniques, the project offers a unique experience for the visitors. Last, but not least, a traditional architectural element; which is the public baths called hammams is reinterpreted with a contemporary design idea. The public baths and pools in this facility are surrounded by digital infrastructures apart from the recycling plumbing system; which creates a compelling ambient that is interactive and artistic (see Figure 10). By using technology and bio-materials, the project offers empowerment, socio-economic betterment, ecological improvement, and reformation in public health.

Project V: 'A-Wave'

Kocaeli is an industrial city near Istanbul. As a consequence of the increasing population caused by local immigration related to production industries and unplanned waste management caused by the factories, marine pollution has increased in the bay due to industrial and household waste. As a result of the nutrition process caused by organic waste, especially in summertime, algae deposits and mucilage occur on the sea surface and produce odors that disturb the public. In addition, the diversity and nature of living creatures in the bay ecosystem are also negatively affected by pollution. Additionally, as a result of being a coastal city, it also affects the city economically, where fishing is an important source of livelihood. Therefore, the 'Awareness Wave: A-wave' project is an architectural complex that proposes a solution for problems related to life under the sea and affordable and clean energy.

It is the innovation of this project that affects both the bay ecosystem and the people of the city. People can participate in the cleaning of the sea and contribute to the process with research and development studies. The project aims to raise awareness for life under the sea while ensuring that the public contributes to the cleaning of the sea at different stages. The technologies used were bioenergy and bioplastic production from marine wastes and real-time data visualization (see Figure 11); therefore the local community can experience the change and gain awareness. This project has three parts: energy production, bioplastic production, and creating awareness of environmental challenges in the local area. Energy production from marine wastes takes place at various points in the bay and provides clean energy for the city. In addition to that, the research & development center headquarters of the project is located in the community center building. There will be a bioplastic production from fish waste (see Figure 11). This production will provide added value to the project thanks to the fish market next to the community center and seafood restaurant in the building. Raising awareness, another part of the project takes place in the experience corridor and theater here. Experience corridor is an interactive area where visitors will learn about sea creatures in the bay through interactive screens and gain awareness by digitally tracking and monitoring sea cleanliness simultaneously. The stage is surrounded by digital screens and the special decoration for each game is intended to be projected through digital screens. In this way, an innovative approach to the theatre experience was proposed by making the audience participate and interact in real-time with the play. The project adapts the current public building into a smart environment by embedding digital data-collection stations in the project area. Both the building and the neighborhood as an interactive environment. This smart system creates a symbiotic bond between the community, the building, and the city which has socio-economic and environmental outcomes.

Figure 11. ‘A-Wave’ Material Production and Energy Management Proposals

While the projects’ objective for the public is to contribute to the environmental sustainability awareness movement; supporting this by producing a spatial response made the process more substantial. The connection between design-driven innovation is that the project both affects the bay's ecosystem and the local community. People can participate in the cleansing of the sea and contribute to the process with research and development studies. Those who don't contribute actively still can witness this process by experiencing the change in the design scenario. The experience corridor designed to raise awareness of the underwater life of the project visualizes the generated information of the environmental transformation by AI and VR, the participants can observe the change in the sea in different categories thanks to the real-time data visualization technology, and they can experience becoming a part of the change (see Figure 12). This project is an architectural example of Industry 5.0 regarding the implied digital technologies in the built environment.

Figure 12. 'A-Wave' Design and Facilities.

DISCUSSION

This paper addresses undergaduate desgin students, by proposing a learning method, which predicates on the Challenge-Based Learning (Apple Inc., 2010); (Nichols, Cator, & Torres, 2016) principles and built upon the fusion of existing classical teaching techniques that are applied to architectural design studio education. However, Industry 5.0 is not only about technology and the transformation of the production line. It includes the digital transformation of the whole business (Fitsilis, Tsoutsa, & Gerogiannis, 2018); relatedly, the aligned learning schema is crucial to be able to adapt to the current technological challenges. More qualitative research is needed to explore and understand the issues, challenges, and future direction of these new technologies to allow more experimental design research for realization. Therefore, we focused on the following technologies that are provided by I5.0 in our architectural design studio, which are shown in the following table (Table 1):

Table 1. Implied Technologies

TECHNOLOGY	***IMPLICATION***
BIG DATA & CLOUD-BASED SYSTEMS	real-time or existing data used for design, data visualization smart built environment
SENSOR-BASED TECHNOLOGIES	data collection and design decisions, real-time interaction, interactive media design, experience design, smart built environment
3D PRINTING, FAB-LABS, DIGITAL FABRICATION	maker culture, fast and accurate production, personalization, low-cost production
ARTIFICIAL INTELLIGENCE (AI)	user experience, presentation of the project and representation of data, real-time interaction, interactive media design, experience design
AUGMENTED REALITY (AR) VIRTUAL REALITY (VR)	user experience, presentation of the project , representation of data, real-time interaction, interactive media design, experience design
DATA VISUALIZATION	user experience, presentation of the project and representation of data, real-time interaction, open - information
SMART MATERIALS AND BIO-MATERIALS	fabrication and using digital technologies to create smart materials & systems, fabrication of bio-materials for living environments, zero-waste, sustainablity and resilience
INTERNET OF THINGS	real-time control, optimization, modeling, simulation, interoperability, interaction, user-experience, smart built environment, physical interaction, interactive design, real-time information
MODELLING TOOLS	advanced modelling skills including parametric design, design optimization, creativity in design
BUILDING INFORMATION MODELLING	data documentation, facilities management, real-time control, optimization, modeling, simulation, interoperability
VISUAL PROGRAMMING SOFTWARES	computational design, optimization, advanced decision making.

The main contribution of the new method is to structuralize an efficient learning technique for architectural design discipline, which is an appropriate education procedure for the current technologiacl challenges and aligns with the latest technologies, actual challenges, and requirements of the information age. To cultivate pioneering and innovative designers, it became necessary to reassess, revise, and adapt traditional design studio methodologies and content. The core challenge is to align the cognitive capabilities of Generation Alpha with the educational frameworks provided by design institutions in order to address prevailing issues. Consequently, the theoretical foundations of the applied methodology within architectural design studios must be shaped by contemporary global challenges and concerns.

The foresight of this study is to expand the perspective through the emerging term Industry 5.0 (European Comission, 2022-A), which complements the existing Industry 5.0 approach by specifically putting research and innovation at the service of the transition to a sustainable, human-centric, and resilient industry. The next industrial development provides a vision of industry that aims beyond efficiency and productivity as the sole goals and reinforces the role and the contribution of industry to society (Kraaijenbrink, 2022). To expand the vision through the upcoming exigence of the industry, adopting a human-centric approach for digital technologies including artificial intelligence. Moreover, up-skilling and re-skilling the AEC practitioners and workers, particularly in digital skills, would be the next challenge. Therefore, the main aim is to develop modern, resource-efficient, and sustainable industries and transition to a circular economy. Lastly, the mass customization and the human-centric approach added to the industry 5.0 would create a globally competitive and world-leading industry, speeding up investment in research and innovation according to European Commission's recent discussions (European Comission, 2022-B). Re-thinking the automation in AEC in a human-centric manner would promote talents, diversity, and empowerment and, therefore, induct a more resilient economy and sustainable approach in various fields. However, several challenges persist, including the need for a pedagogical shift and the technological proficiency of students within this approach. Incorporating Industry 5.0 principles into architectural design studio education demands a transformation in teaching methods. Educators must design curriculums and syllabuses that integrate technology fluidly into the design process while fostering creativity and critical thinking. Additionally, the integration of advanced technologies requires ensuring that design students are adequately skilled in the use of digital tools, which necessitates investments in training programs and access to appropriate hardware and software.

CONCLUSION

In this paper, we analyzed the perception of the impact of I5.0 on the AEC industry from an academic point of view. Our main contribution is that we show how these technologies are used and seen in an emerging interest in the research field; since most of the studies on this matter have been conducted in the architectural design discipline together with current digital tools and technologies.

Even though the current architectural design understanding includes being a 'machine for living in' (Corbusier, 1923), yet, it requires much more than that. Right along with the digitalization movement in every industry, the possibilities of creation have been extended their limits too. Currently, architecture is not a 'tree' (Alexander, 1965), not a 'space' nor a 'machine'. It is a system that augments and promotes the living experience. Concerning the current digital progress of today's world and the ***'****understanding'*, the design is mostly *digital* (Negroponte, 1995-B); *interactive - responsive* (Fox & Kemp, 2009)**;** *and should act as a living system* (Ratti & Claudel, 2016). Relevantly, the new concept and the proposal of 'Advanced Architecture' (Gausa, Guallart, Müller, & Cros, 2003) topics that go beyond the classic 'form and function', but adding an extra layer of complexity regarding its' interaction with users, that comes with environmental concerns, backed up by the power of data and also within the users' role and responsibility in the digital age. The new architectural design understanding covers sustainable development goals and global interests responsibly by using current technologies.

As a matter of fact, Industry 4.0 and 5.0 provided efficient tools that enable the practitioner to imagine, design, and produce innovative artifacts towards social and environmental sustainability. Therefore, thanks to I5.0, recent research & development proposes design solutions that enable enabling a circular economy, regulate social practices, and productive corporate purposes. Relatively, our research outcomes clearly show that the implications of digital methods and Industry 5.0 in the design studio contexts augment creativity and extend the limits of imagination in multi-disciplinary ways. By focusing on human-centric approaches and seamless collaboration between humans and machines, Industry 5.0 aims to enhance productivity, foster innovation, and address ethical considerations.

The impact of I5.0 in various disciplines, especially in architectural design, is essential, and therefore, implementation of I5.0 strategies in the academy is crucial to boost productivity and enhance design-driven innovation. This transmission that we addressed in our design studio involves several key aspects such as human-machine collaboration, user-centered design, holistic benefit of society, and therefore the ethical concerns regarding the public. In Industry 5.0, architectural design studios can embrace a collaborative approach that integrates human skills and creativity with advanced technologies. Designers can leverage digital tools, such as computational design, parametric modeling, and virtual reality, to augment their creative capabilities. By collaborating with machines, designers can explore innovative design solutions, optimize performance parameters, and enhance the overall design process. Architectural design studio education in Industry 5.0 focuses on empowering designers with the necessary skills to effectively utilize advanced technologies. Designers need to be trained in the use of digital tools and understand their potential applications. Additionally, they should develop critical thinking and problem-solving skills to effectively interpret and analyze the data generated by these technologies. This empowerment enables designers to harness the power of technology while maintaining their creative vision.

By embracing the collaboration between humans and machines, architectural design studio education in Industry 5.0 enhances designers' capabilities. Digital tools enable designers to explore complex design possibilities, simulate real-world scenarios, and test performance parameters, leading to more innovative and optimized designs. Moreover, the integration of advanced technologies in architectural design studio education can facilitate the creation of sustainable and human-centric designs. By leveraging computational analysis and simulation tools, designers can optimize energy efficiency, daylighting, and thermal comfort, creating architecture that is both environmentally responsible and responsive to users needs.

The integration of advanced technologies in architectural design studio education can facilitate iterative design processes. By leveraging computational design tools and virtual environments, designers can explore multiple design iterations rapidly, allowing for a more thorough exploration of design alternatives. This can lead to the discovery of innovative solutions, improved design iteration, and the optimization of design performance parameters. Industry 5.0 emphasizes the collaboration between humans and machines. In architectural design studio education, this collaborative approach can extend to improved communication and collaboration among design teams.

The transmission to Industry 5.0 involves harnessing the power of data and analytics. In architectural design studio education, this can translate into the integration of data-driven design approaches. By utilizing sensor data, environmental simulations, and performance analysis, designers can make informed design decisions that optimize energy efficiency, occupant comfort, and overall building performance. This integration of data-driven design approaches can result in more sustainable and responsive architectural solutions.

As Industry 5.0 emphasizes the integration of human skills with advanced technologies, architectural design studio education can place a stronger emphasis on cultivating design thinking skills. Designers need to develop a deep understanding of human needs, social context, and environmental considerations. By incorporating design thinking methodologies, such as empathizing, defining problems, ideating, prototyping, and testing, students can become more adept at addressing complex design challenges and creating human-centric architectural solutions. With the advancement of technology, architectural design studio education should also address the ethical and social implications of design decisions. Designers must be aware of the potential impact of their designs on various stakeholders and the broader society. By incorporating discussions on ethics, social responsibility, and cultural sensitivity into the educational curriculum, architectural design studio education can foster a generation of designers who consider the broader societal implications of their work.

The hypothesis suggests that integrating Industry 5.0 principles into architectural design studio education will enhance design skills, leading to the creation of more sustainable and innovative architectural solutions. This approach—and the hypothesis behind it—could provide a foundation for further research and practical investigation into the impact of Industry 5.0 in architectural education, assessing outcomes in terms of design quality, sustainability, and human-centered values. In essence, this method opens the door to better design iteration and exploration, stronger collaboration and communication, the adoption of data-driven design, the development of critical design thinking skills, and a deeper awareness of ethical and social concerns. These advancements can ultimately help shape sustainable, innovative, resilient and people-focused architectural solutions.

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