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Natural Intelligence: Criticizing Architecture in the Digital Age

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Abstract
We are currently living in the post-fourth industrial revolution era where digitalism and machine learning dominate our everyday ecology. Within architectural education, students are developing different digital techniques to express their projects in terms of plans, sections, elevations, and 3D models. Yet, with all this advanced level of information, there is a gap when it comes to critical thinking. This paper aims to put forward the foundational steps towards analyzing and criticizing architecture with the addition of a human perspective to consider the natural surroundings' intelligence in the design morphology, materiality, and fabrication that is subject to digital infrastructure. The objective is to highlight the students' cognitive skills reinforced with digital thinking as a way to move further steps ahead of the trending market.
Keywords: Nature; Bio-Learning; Bio-Organism; Artificial Intelligence; Critical Thinking; Growth

1. Introduction

"We live in a special time in history, a rare time. A time when the confluence of four fields is giving designers access to tools, we never had access to before Computational design, additive manufacturing, materials engineering, and synthetic biology" said Neri Oxman in a TED Talk in 2015, surmising the whole role of the fourth industrial revolution (4IR). Unlike the previous industrial revolutions; the first revolution with the discovery of coal and steam engines, the second with machines and mass production, and the third with the beginning of digitalism and computers; the fourth industrial revolution is considered a unique fusion between materialism, digitalism, and biology. (Cole, 2020).
This revolution is natural and biologically driven. The advancement in biotechnologies and studies of natural behaviors altered the technological and computational industries from one-way approaches to the advances of circular economy in diverse aspects, as well as fabrication and material experimentations from assembly methods to additive methods.

This led to a complete shift of paradigms when it comes to architectural design, materiality, and manufacturing. From Louis Sullivan's "form follows function", the traditional uses of cement and reinforced concrete that has their limitations in both design and fabrication, to 4IR marking a huge leap in design approaches and architectural fabrication. Advanced technologies and techniques of 3d printing and generative computational modeling increased the level of design complexity from 2 dimensions, 3D and even 4D to the matrix of dimensions that exceeds the creation of the spatial design to the creation of a wholistic space intervention that enables the growth of surrounding nature with ensuring full functionality of the space as a way of creating coexistence with nature. This generates a novel user experience affecting one's psychological and physical health and opens new horizons for understanding natural behavior and adaptability.

However, when it comes to architectural education, there is a huge gap between the rapid transformation and advances of design methodologies; which in turn affects the professional practices of architecture and the methods of teaching in design studios. The main contrast lies in the way architectural criticism has been practiced within architectural studios. According to Ceylan & Soygenis (2022), the unclear criticism criteria in design studios prevents students from creative thinking as they are the only recipient of the critique and not the dominant ones. The authors of this research paper put forward the role of cognitive critical thinking in the digital era of architecture that enable students not only to keep updated with the constantly shifting environment but also to have intellectual and professional input on the different interventions happening daily. There is a strong emphasis on teaching students complex skills over software (Hulin, 2018) in terms of strengthening social networks and establishing solid grounds for authentic criticism.

To improve the cognitive skills of the students, the practicing of criticism in design studios should be taken beyond student–teacher subjective limitations (Utaberta, Hassanpour, Handryant, & Ani, 2013) shifting towards an objective criticism from a more natural–human point of view. Concerning architectural pedagogy and the process of gaining cognitive skills for students this process mainly happens throughout design studios, i.e. sketching, writing, and visual analogy (Ceylan & Soygenis, 2022).

2. Material and Methods

This paper uses descriptive methods to define the impacts of AI and post fourth industrial revolution on critical thinking in architectural education, along with an analytical comparison of students' projects using old and 4IR-adapted critical thinking methods. Finally, the paper suggests basic strategies for enhancing cognitive skills for architecture students reinforced with digital thinking to bridge the gap between architectural pedagogy and the trending market.

2.1. The fourth industrial revolution and the Age of Digitalism effects on architectural design

The fourth industrial revolution is considered a significant leap in technology, especially with the exceptional development that is happening with artificial intelligence technology at an unpredictable growth rate in the past decade. That altered many paradigms in the architectural industry from concept generation to the post-completion phases of the project. With the rapid growth of computational and generative design tools, designers and architects have access to unlimited potentials and possibilities even in the manufacturing process that is constantly overcoming restricted structures and fabrication limitations. Moreover, the metaverse architecture powered by blockchains, NFTs, and cloud technologies, changed the human-space interaction experience through the advancement of augmented reality (AR) and Virtual Reality (VR); which altered the human perception of architectural space. The fabrication techniques alteration from assembly to additive methodologies with the advancement of 3D printing machines and robotics gave freedom in experimenting with different design forms and morphologies without limitations, revealing a new horizon for material experimentations and natural-based materials explorations, specifically with the advancements in biotechnology that all lead by the fourth industrial revolution.

2.1.1. From the One-way Approach to a Circular-based Design

The key contrast that differentiates the fourth industrial revolution from other industrial revolutions is the transition from; assembly steps; a linear approach focusing on certain objectives, towards the creation of a matrix of intersected approaches exceeding machinery and smart technologies to simultaneously fusing those technologies with materiality, digitalism, and biological aspects. Klaus Schwab in his book defines the Fourth Industrial Revolution as the era that "creates a world in which virtual and physical systems of manufacturing flexibly cooperate at the global level" (Schwab, 2016). Applying this definition to the architectural industry gives a wider scope for the development of architectural design aspects and morphologies to meet natural needs in integration with human needs beyond aesthetics. The aim is to build up layers of complexity in the design to increase functional efficiency while reducing the carbon footprint and waste to zero (Kia & Mahdavinejad, 2020); and creating a type of architecture that acts like an autonomous micro-climate to be integrated within the ecosystem. As this concept sounds ambitious, the current integration of AI assets, chatbots, and visualizations into architectural computational programs and the emerging additive fabrication shortened distances to become reality (Andréen & Soar, 2023).

2.2. Natural Intelligence (NI) to Artificial Intelligence (AI)

Natural Intelligence (NI) is an autonomous form of intelligence recognized in biological creatures and organisms in nature to sustain and adapt to their natural environment aims using their innate behavioral schemes (der Malsburg, Stadelmann, & Grewe, 2022). Unlike AI, NI is far more complex in its abilities for rapid learning, adaptability, sustainability, and generalization capabilities while maintaining autonomy and creativity. This complex build-up of behaviors and actions is simplified to the idea of *"network self-organization",* which describes a series of cycles between emerged connections supporting random activity, then reconnected with a different network through "Synaptic Plasticity". And the cycle goes on tell it approaches a static state which means reaching its goal (der Malsburg, Stadelmann, & Grewe, 2022).

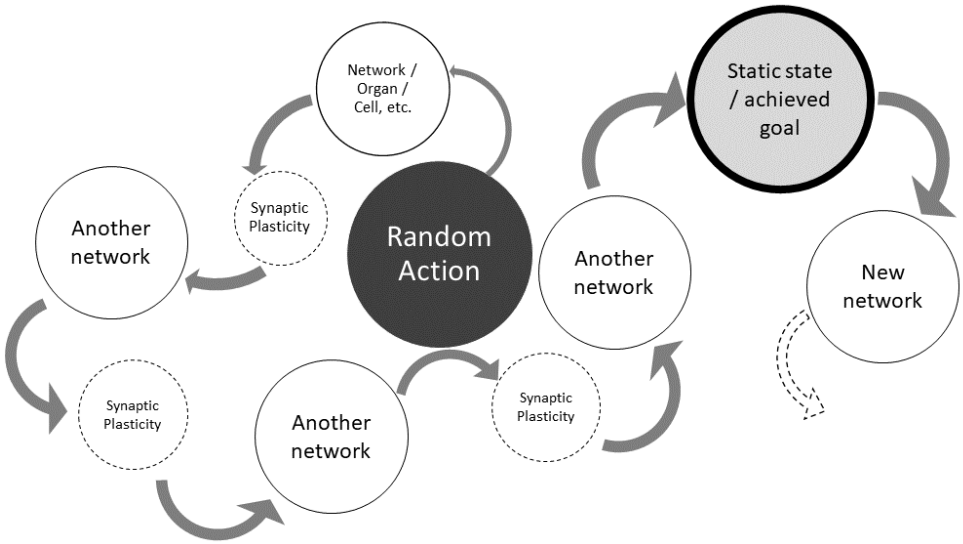

Figure 1 Illustrated diagram visualizing the network-self organization idea (der Malsburg, Stadelmann, & Grewe, 2022); (Illustration developed by the authors).

This network-self-organization behavior is found in the slim mold as well as in the human eye. As illustrated in Figure 2, the slim mold, *"Physarum polycephalum"* perfectly represents self-organization networking behavior that is further studied as a core axon in swarming intelligence. As the cells of the slime mold reach out in a random direction as a way of random exploration for the nearest source of food. The cells later after cycles of networking and reconnections identify the targeted source of food and redirect other cells towards the right way (Boussard, et al., 2021). These cognitive skills are also found in the human eye in different approaches. Cycles of networking and connections go back and forth between the eyes and brain to complete the fragmented pieces of information perceived by the eyes to have a full vision (der Malsburg, Stadelmann, & Grewe, 2022). This additive manner is a key axon in the fourth industrial revolution.

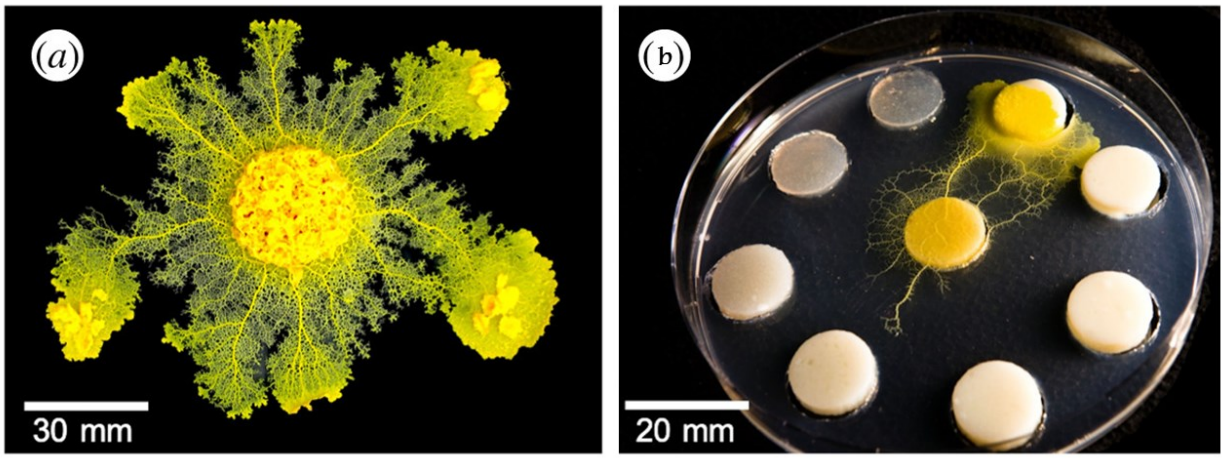

Figure 2 (a) Slime mold moving in random directions in exploration for food sources, **(b)** Slim mold identifies the suitable source of food among different options and directs the rest of the cells towards it **(Boussard, et al., 2021)**.
Hence, the idea of training artificial intelligence bots and technologies on diverse natural intelligence cognitive skills and growth behaviors can be applicable. How many alterations will occur to the architectural design process, morphology, materiality, and even functionality?

Looking back finding that NI was the main inspiration for the emergence of AI. AI first came into existence by John McCarthy in 1956, to equalize the machinery systems with human mind intelligence (Bøgehøj, 2016). It was categorized into Artificial General Intelligence (AGI), where machines were trained to behave automatically as humans in certain tasks. Additionally, Applied Artificial Intelligence (AAI) is also an integral part of the digital family tree, yet it is limited to certain commands ordered by the user or programmed (Bøgehøj, 2016). However, recently AI big data (BD) has grown drastically in a way that significantly changed the contemporary design paradigms, adding a higher level of complexity

when it comes to nature and architecture integration and changing the perception of spatial user experience with augmented and virtual reality.

2.3. Critical Thinking and Architectural Education in the Digital Age

Architectural design is a highly complicated solution-finding process. It acquires architectural pedagogy and intense training for critical thinking through multiple critique sessions within architectural studios (Utabertaa, Hassanpour, Handryant, & Che Ani, 2013). However, when it comes to architectural education there is a notable gap between the rapid transformations, advances in technologies, and computational design in contemporary architecture led by AI and machine learning, which in turn affects the professional practices of architecture, and the ways of teaching in design studios. The main contrast lies in the way architectural criticism has been practiced within architectural studios. According to Ceylan & Soygenis (2022), the unclear criticism criteria in design studios prevents students from creative thinking as they are the only recipient of the critique and not the dominant side. In addition, the misconception of surrounding nature and its relation to architecture is no longer just an added value to design, but a critical necessity for the current architecture. Hence, its objective is not only to adapt to the surrounding nature as in mere co-existence with human creatures and indirect users for the architecture but also it aims to become an integrated part of the ecosystem and to co-host nature with humans.

"An architect's role should be more of an activist. Architects must stop waiting for commissions from wealthy clients and priorities designing for the planet." Says Yasmin Lari, RIBA Royal Gold Medal Winner 2023.

Therefore, a complete change in the criticism methodology and criteria should be done in consideration of rapid technological changes, for decarbonizing our current architecture, understanding the co-existence with nature, and influencing the user's acceptance of coexistence with nature as a necessity to preserve their life and maintain their physical and psychological health.

2.4. How can merging the Fourth Industrial Revolution's (4IR) circular design theory with Natural Intelligence (NI) can enhance the cognitive skills for critical thinking within the design studio?

To answer this question, an overview comparison between two groups of projects to test students' understanding of their proposed concepts, form generation phases, and the evaluation criteria throughout the design process. Both groups are projects for architecture students in the 5th semester, spring semester 2023, at the same university in Cairo, Egypt. Group A consists of two individual projects in their third-year design studio. Throughout the semester, they were assigned to design a UNESCO Headquarters in any coastal area, with no location restrictions; and part of the design is to be designed underwater. Group B consists of one group project as an outcome of a two-day intensive workshop entitled "Ocean Intelligence" where the students were assigned to suggest solutions and redesign the area of El-Max in Alexandria, Egypt.

2.4.1.1. Group A – Project 1: **UNESCO Underwater Headquarters in the** Royal Port region in Jamaica

The Royal Port region in Jamaica, South America, is the first student-chosen location. He roughly went through the history of Royal Port Jamaica fixating on the historical importance of the area as a diamond preservatory and the sunken pirate city, that became a familiar tourist diving spot.

Going through the project concept, the student chose the diamond shape and rigid lines as his main design concept. It was then followed by a process of reforming the diamond shape to fit with the project's program needs from a certain number of offices and other required facilities. The student's thinking was primarily oriented towards developing the 2D top view plans seeking the optimum solutions in the relations between the main components of the projects which are the UN offices, the administration area, and the underwater scientific laboratories and museum, in terms of circulation, mobility, proximity, needed ventilation, and natural lighting. Giving less attention to the vertical relations and the relation between the project and the surroundings resulting in an extruded building mass with diamond-shaped panels on the façade referring to his main concept.

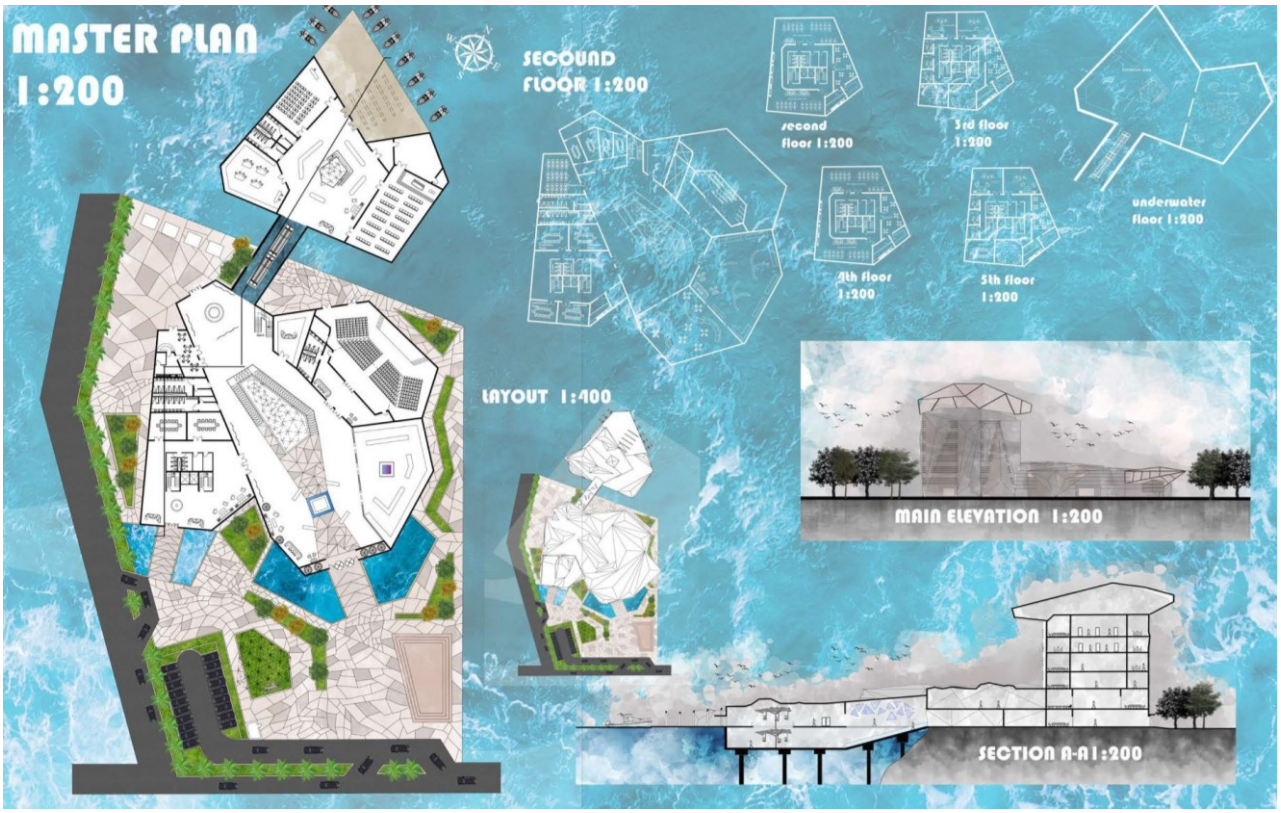

Figure 3 UNESCO Underwater Headquarters in Royal Port region in Jamaica **(Student "1" Project Final Submission)**

2.4.1.2. Group A – Project 2: UNESCO Underwater Headquarters in India

Unlike the first project in this project, the student focused on designing the exterior of the building mass and façade and later designed zone relations, circulation, and vertical relations. This student's project chose to locate it in India; therefore, he chooses a lotus flower shape combined with the jellyfish morphology as his source of inspiration. His focus was on the aesthetics of the design, giving attention to utilizing the shape of the jellyfish tentacles to create the external structure for the project as well as a shading element. The student reformed the lotus petal pattern vertically as glazed panels on the façade. According to the student's project description, he used green roofs in certain areas of the project and an open core to enhance the sustainability of the building by reducing the heat inside the building and therefore reducing the energy consumption of the building.

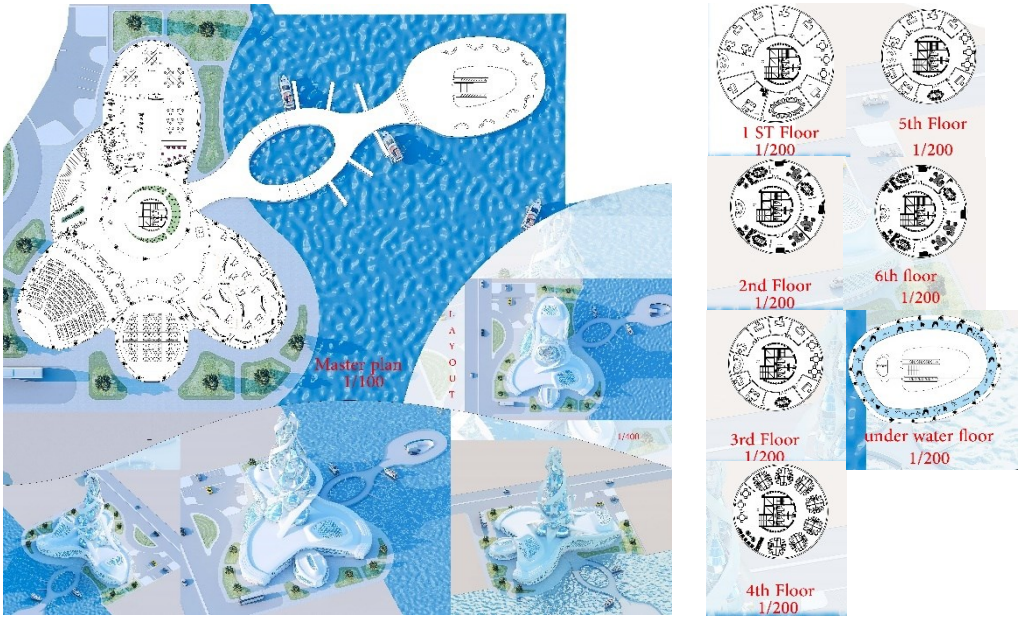

Figure 4. UNESCO Underwater Headquarters in India – (Student "2" Project Final Submission)

2.4.2. Group B: El-Max Revive

As mentioned above the outcome is done in two intensive consecutive days of workshop. The workshop's main aim is to learn and experience designing for co-existence between humans and nature; focusing on oceans and marine life. Given El-Max canal on the Mediterranean Sea is a complex problem that goes beyond air and water pollution; caused by nearby oil and cement factories; reaching the residents of the area's health and majorly impacting their source of income as fishermen.

Students' solutions took three approaches, restore, regrow, and reconnect. Restoring the ecosystem through different techniques of air and water cleaning and filtering systems, merging between manual collecting systems in contribution to the local community, and high-tech systems using swarming robots to collect plastics and trash from the canal and the coastline.

Recycling the collected plastics into 3D printed; Gyroid shaped walls and structural elements for several reasons. First, most of the buildings in El-Max are semi-deteriorated and need restoration, especially on the facades. The gyroid form gives the same strength as solid walls using less material, therefore, creating air gaps inside the wall reducing the heat gain thus reducing the temperature inside the building. Second, the El-Max area before the major environmental changes used to be a resting area for migratory birds, due to pollution, birds are rarely seen within the area. Due to time limitations, the students suggested doing further studies on the type of birds migrating, their nesting and breeding behavior, all their essential needs, and what if the gaps of the gyroid form on walls became their nests, Could it be an added layer of protection on the wall as well as a heat installation? Another suggestion is to also study the native plants of the area, what if some seeds are printed in certain areas in the wall will it grow creating vertical gardens on façades? Would it help in purifying polluted air?

Regrow the surrounding natural environment on land and underwater. The solution suggests designing sea scape using artificial reefs on the coastline and Bio-Rock tiles; inspired by Bio-Rock technology invented by the futurist German architect Wolf Hilbertz in 1976; to regrow mussels, seashells, and algae as natural water filters and create a microhabitat for marine life thus providing sustainable fishing source for the local community of fishermen. Furthermore, the artificial reef structure mitigates sea wave energy impact which protects the coastline from erosion and drowning hazards in the long term.

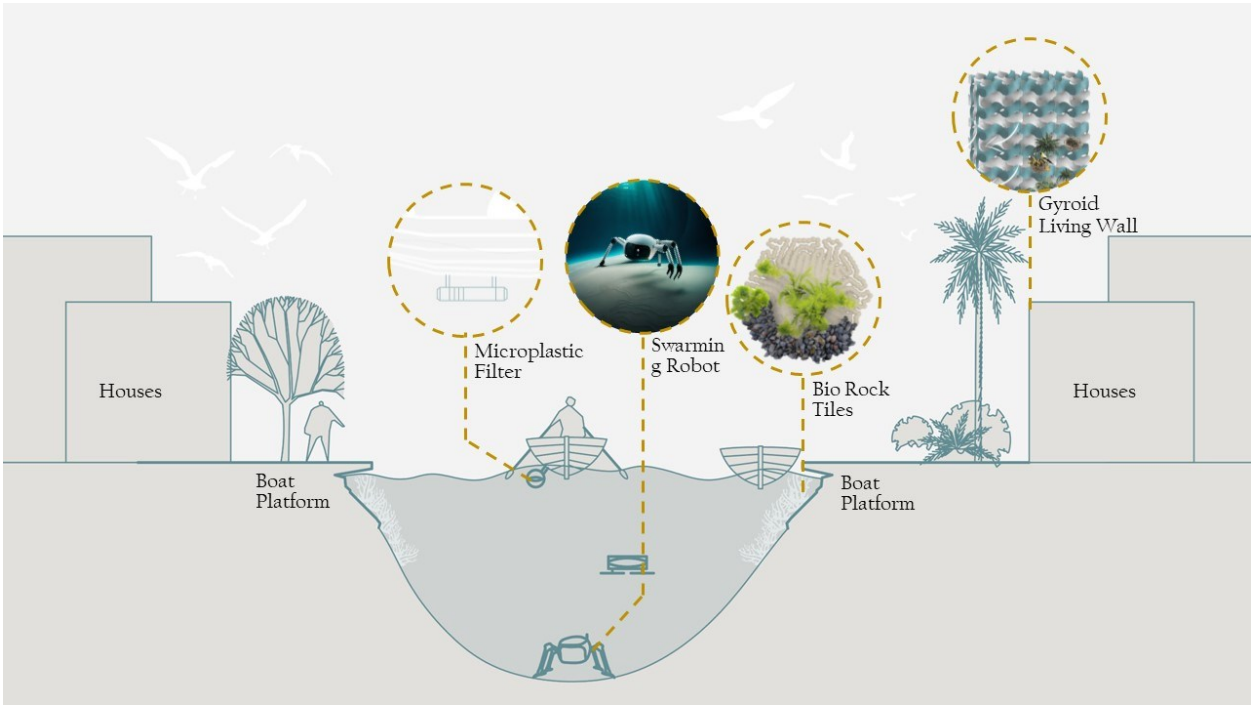

Figure 5 Part of Project Revive El-Max illustrating the suggested solutions to restore the area **(Group Project).**

Reconnecting humans with nature through the co-existence with the surrounding non-human citizens. Understanding that our own lives and source of living are dependent on the life of nature. As a reminder for the human citizens and a major part of the regrowth of surrounding nature in the project, the students designed a recreational area on the

coastline consisting of a landscape connected with a seascape for the local community to have a space to meditate, enjoy clean air and prosperous nature.

Figure 6 Part of Project Revive El-Max illustrating the suggested sea-land scape recreational area (Group Project)

2.4.3. Comparison Results

Both students in group A, despite each one of their design processes, both projects were pure mimicking and imitations of certain shapes found in the nature, culture, or history of the chosen locations. This means their understanding of the concept is excluded within the project form and shape regardless of the functionality of the project or even relations between the project and the surroundings.

The attention to technical 2D plans in the 1st project took a whole semester to get developed with very less attention to other environmental aspects or studies of the impact of the design on the surrounding environment and vice versa. Also, the second student took the other way around starting with 3D and back to 2D both projects and both projects met at the same point where their understanding of a concept is just an aesthetically pleasing form and for it to become sustainable is by exclusively using green roofs and some passive ventilation techniques and natural lighting.

These are just two examples representing a full batch of students undergoing the same “dictatorial criteria” where only the design studio instructor and assistant are allowed to criticize the projects. Unfortunately, those criteria depend on marking projects based on the aesthetics of the project, the technical 2D plans and sections, if the project fitted all the program requirement, the circulation and the relationships between zones and sustainability is often a bounce yet represented in green landscapes, roof, and LEED passive systems. The options for building materials are limited to steel, reinforced concrete, and the use of glass mostly on the façade. Regardless of the climatic zone from which the project is located the environmental impact of the use of such materials and even whether it’s available in those regions or not. Those issues occur since students are not encouraged to research or experiment using different materials or tools throughout the design studios yet are forced to strictly follow the feedback of their instructor line by line which again focuses on the plans and technical drawings that are seen in the final project. One final issue, students are not encouraged to brainstorm or work in groups, they are not even allowed to criticize each other which limits the student’s thinking process to the instructor’s point of view exclusively designing with the instructor’s methods rather than creating learning how to create his own design identity.

Besides learning the co-existence with nature, the workshop was a test for a completely different set of criteria to be applied within the design studios and answering the question: How can merging the 4IR circular design theory with NI can enhance the cognitive skills for critical thinking within the design studio? The workshop merged the concept of synaptic plasticity and circular-based design strategy influenced by the fourth industrial revolution. Hence, the importance of group work. The students were encouraged to search for solutions in different directions. Brainstorm their ideas and gathered thoughts and discuss their implementations and how it gets connected. In this workshop, students had the opportunity to learn from multi-disciplinary experts in the fields of robotics, marine biology, and space-

architect as well as primely learning to design within extreme environments. Learning and working with different fields other than fellow architects and colleagues, emphasized the idea that everything is connected whether direct or indirect. Therefore, the design shouldn't be autonomous from its surrounding as well.
The students were encouraged to develop their designs with AI tools and advanced computational software which helped them to visually represent their ideas in such limited time and gave them more time to develop their concepts and ideas.

Another aim of the workshop is to teach students how to become activists by actions whether ocean or environmental activists. And to design for a cause, seeking a better future for humans that starts with a better future for Earth. For that reason, and since this workshop is aimed to design for the ocean, a session was given to understand marine life ecology, how it was, what problems it's facing, how it became, and how our lives as humans depend on its revival. So, their connection and understanding of the ocean became deeper and their search for a solution became sincere which in turn become fixed in their minds how their designed architecture can weather save the co-system or continue corrupting it.

3. Strategies for enhancing cognitive skills for critical thinking in design studios

From the previous comparison, the strategies to enhance cognitive skills in design studios are concluded as follows:

i) Encouraging collaborations and group work among students.
ii) Encouraging research and experimenting with different novel materials, design morphologies, and updated computational and generative tools.
iii) Encouraging collaborations with different fields and inter-disciplines.
iv) Engaging students with the tackled problems
v) Understand the co-existence of nature and non-human creatures.

4. Conclusion

The post-4IR era has brought significant advancement in the field of architecture, driven by digitalism, artificial intelligence, and a deeper understanding of nature and biology. However, there is a noticeable gap in architectural pedagogy when it comes to critical thinking. This paper has highlighted the importance of integrating the circular-based design with the natural intelligence of synaptic plasticity networks in enhancing the cognitive skills of architecture students allowing students to design nature-inclusive architecture shifting from designing for structure, and function of a dead building towards the creation of living architecture.

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Conflict of Interests

The authors declare no conflict of interest.

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