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Integration of Digital Tools in an Architecture Studio and its Impact on Student Learning

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Abstract:
Architectural design is evolving due to various approaches embracing advancing digital technologies, which utilize various modern tools across technical domains. Architectural design education across Pakistan cannot effectively incorporate computational design courses into its curriculum. Therefore, students depend on relatively traditional design methods for their architectural projects. They struggle to cope with the rapidly evolving architectural trends and strive harder to compete in the field. *This paper evaluates how the digital design process employs novel and creative computational methods involving CAAD.* This paper examines the digital culture surrounding intricate and complex design systems, presenting them in a simplified manner. It aims to assist the design processes undertaken by educational institutions and architectural professionals. By departing from the conventional, traditional design methodology, the paper explores and evaluates design processes expressed in a distinctive style that enhances student learning and engagement. The paper discusses learning theories in literature and how captivating design methodologies in studio settings involving computer-aided architectural design apply these theories that enhance the student learning curve within the design studio.

Keywords: Student learning, CAAD, digital Tools Integration, Studio Education

Introduction:

In the realm of Architecture, Computational Design is a multidisciplinary subdiscipline that uses advanced computing capabilities to solve complex architectural problems, develop innovative design solutions, and create efficient work interfaces. It can be defined as a design method that uses a combination of algorithms and parameters to solve design problems with advanced computer processing.(Nilsson & Msa, n.d.). Each step of a designer's procedure is interpreted into coded computer language. The software program uses this data and project-specific limitations to create algorithms that produce design models or comprehensive analyses.(Rogers & Schnabel, n.d.-a).Although computational design has spread worldwide, it has progressed relatively slowly in Asia. Students in Asia are introduced to CAAD software after two years of working with traditional methods. Teaching pedagogy cannot fully address these CAAD tools to the students, resulting in a lack of utilization in their academic projects. Students are not thoroughly aware of the benefits these tools can provide them to design projects efficiently and accurately.(Rabee M. Reffat, n.d.). According to the research(Varinlioglu et al., n.d.), Digital design tools and CAAD techniques have revolutionized the role of architecture. With the shift from conventional design modes to more advanced tools and techniques, architects can foster more creativity in design projects with a more predictable approach. Current design tools have concentrated on design processes that are mediated by computation. Different design techniques have emerged as the contemporary world evolves and uses design innovation for architecture. Digital technology accounts for the final design form, structure, and materials from design inception to the project's final documentation. This research will explore studio projects based on CAAD and the integration of digital tools to evaluate their impact on and enhancement of student learning in studios, as compared to conventional methods applied in studios in Pakistan. A crucial aspect of advancing student learning is the emphasis on experimentation and exploration(Rogers & Schnabel, n.d.-b). Incorporating digital design tools, like parametric modeling and visual programming, has allowed students to engage in more iterative and interactive design processes. Rather than solely focusing on the outcome, students are motivated to continuously tinker, test, and refine their designs, cultivating a more dynamic and responsive approach to the design process. Another essential element is the development of critical thinking and problem-solving skills. Digital design tools often require students to grapple with complex algorithms, simulations, and data visualization techniques(Nilsson & Msa, n.d.). This encourages students to think deeply about the implications of their design decisions, analyze data, and make informed choices based on the thoughtful feedback they receive. This paper explores how integrating computer-aided architectural design and digital tools has impacted the learning process in architectural studios. This paper explores how emerging technologies have transformed the design process, empowering students to develop new skills and shaping the overall learning environment compared to traditional methods. It delves into how integrating diverse digital tools and computational methods within architecture education can cultivate a comprehensive knowledge base. The paper examines how digital design workflows, data analysis, and simulation techniques can expand the traditional boundaries of architectural practice and scholarship. Furthermore, the paper investigates the methods and tools for digital knowledge acquisition within trans-critical pedagogy, such as parametric modeling, data visualization, and virtual prototyping. The discussion underscores how these digital approaches contribute to a holistic, data-informed understanding of the built environment and its context. This research presents case studies that showcase how specific digital tools and technologies have been incorporated into architectural education. It analyzes the benefits and challenges of adopting these tools and their influence on student engagement, creativity, and critical thinking abilities.

Research Objectives:

This study explores contemporary studio learning theories and how they are implemented in the architecture studio. It also examines the impact of using CAAD and digital tools, analyzing how this methodology differs from conventional methods and how it enhances learning in an architecture studio. The paper begins by providing an overview of Trans critical Pedagogy, emphasizing the importance of critical inquiry, reflective practice, and civic engagement in architectural education. Three studio projects are discussed in detail to analyze how traditional and digital teaching methods differ and what opportunities these digital tools offer for students' learning and development.

Research Methodology

This paper examines the use of CAAD and digital tools in Architectural Design Studios, exploring their impact on student learning by analyzing three studio projects. It compares traditional studio methodologies to understand the differences in learning approaches. The paper delves into how trans-critical pedagogy is implemented in these studio projects, often involving collaborative work among students from diverse backgrounds. This fosters the integration of various perspectives and the challenges that arise from such an approach. The paper then details the studio process, highlighting two key phases: analytical understanding and creative decision-making.

The paper delves into how students navigate between analytical and creative thinking within the studio setting, offering insights into this dynamic process. Furthermore, the paper examines how the inquiry-epistemic component is incorporated into the studio environment with the help of an existing studio framework for digital architectural studios. It explores how knowledge of Transcritical pedagogy and other learning theories can be disseminated with a studio framework designed to teach a studio.

Literature Review

The evolution of pedagogy since the beginning of the 21st century is primarily evident due to the integration of digital tools and technologies.(Nilsson & Msa, 2019). Computational architecture evolved in the architectural industry a few decades ago, but it has progressed to provide ease in this field. Through computational architecture, the design process combines algorithms and parameters to solve design problems with advanced computer processing.(Rogers & Schnabel,2022). Every step of a designer's process is translated into coded computer language. Soft wares then utilize coding methods to convert provided information into algorithms, which are converted into various design models. With the help of this initial programming, architects can generate designs that are both dynamic and repeatable. This power of programming has allowed architects and designers to provide better design solutions as they can now explore hundreds of design options rather than just a few manually generated ones.(Salman et al., n.d.). Using code languages in architecture has induced creativity in the design process. It has also brought improvement in the design and research process. According to recent research(Kolarevic, 2003), Architecture education in the 21st Century faces the challenge of preparing future archives to address unique environmental, economic, social, and political issues. These challenges include global warming, globalization, diminishing natural resources, and aging populations. At the same time, unprecedented opportunities have been brought about. And most extensive information technologies, new materials, and innovative building practices. Kalay argues that architectural education must evolve to equip students with the DNS standing of these things and tools to address them. They are integrating new learning methodologies and promoting a knowledge-based approach to design. Educators must guide students in leveraging new materials, methods, and digital tools to create a state with innovative architectural solutions. By doing so, arguments for education can ensure that future professionals are not always screened contemporary but also capable of leading research and design initiatives that will shape the built environment Responsibly and effectively (Kalay,2008)

Digital tools and their Application:

Rhino 3D provides a range of digital crafting tools that simplify the fabrication of shapes. The

Loft command allows users to generate a surface by fitting it through selected profile curves, defining the surface's shape. The Knot command helps users easily manipulate control points, dealing with the degree numbers of curved surfaces. The Framing helper, a Rhino extension, enables effective camera framing in large-scale compositions. Grasshopper, another Rhino extension, utilizes Python codes to enable users to quickly combine circuits and adjust parameters, effortlessly modifying the shape and parameters, with the code written on Grasshopper modules automatically drawing on Rhino. Ladybug, also a Rhino extension, assists students in analyzing sun paths, sun hours, and wind, saving time. These digital tools empower students to explore curves in architectural design, fostering the creation of innovative and creative architecture efficiently and with reduced errors. The shift towards digital tools was a cultural necessity rather than adopting parametric architecture. Adopting digital design tools in architectural education has also transformed the collaborative aspects of the design process. Architectural design is a problem-solving process (Lawson, 1994), and creating a practical building form must adapt to the project-specific requirements and constraints (Corolla, 2018). However, the socio-industrial and economic context may lead to indefinity, resulting in vague design problems where additional requirements may arise without standard design explanations (Hudson, 2010).To solve these vague problems, digital tools emerged not only as saviors but also as indicators of the complexity that we can find, for example, in calculating structures, ecological responses, form generation, or using a set of politically or socially contextual data. (Laurent Lescop, 2022). Integrating all the digital teaching became the main subject of teachers and researchers. They focused on using computer applications to design and refine students' skills and aptitudes. Today, applying a BIM format, a Grasshopper definition, the analysis of a solar, thermal, or aeraulic phenomenon, procedural modeling, and even creating a rendering image requires us to recognize and grasp the process to authenticate the results. The teacher must know the procedure in order to be able to assess the result precisely. In our universities, there is a lack of ability for process evaluation(Asghar & Naqvi, 2021). However, until now, there has been no framework or essential structure for using computers in architectural education. Most architectural schools and departments, especially in advanced countries, have established their criteria in the educational schedules by integrating more computer courses(Kalay, n.d.). Computational technology has revolutionized the world in recent years, also changing the traditional context of architecture as a profession and in education.(Koch Katherine 2002). However, its advancement in Asia is perceived to be limited due to a lack of awareness about the use, benefits, and implementation of computational tools at both undergraduate and professional levels. This is exacerbated by students' lack of professional training opportunities, the unavailability of computational software, and an absence of structured curricula that include CAAD tools. Consequently, students perceive pursuing computational architecture as complicated, hindering their chances of exploring CAAD. As a result, its implementation remains limited in the practical field.(Asghar, 2023).To address this challenge, architecture schools must actively incorporate computational design methods into their curricula, providing students with the necessary skills and knowledge to navigate the evolving field of architecture.

Student Learning Framework in CAAD Studio: Learning is a multifaceted journey involving various theories and approaches. From the behavioral perspective, learning is shaped by external factors, where reinforcement and punishment play a crucial role in modifying behavior.(Iqbal & Roberts, 2019) .Conversely, cognitive learning emphasizes the mental processes of gathering, storing, and recalling information, highlighting the importance of understanding how students process knowledge.(Iftikhar et al., 2018).

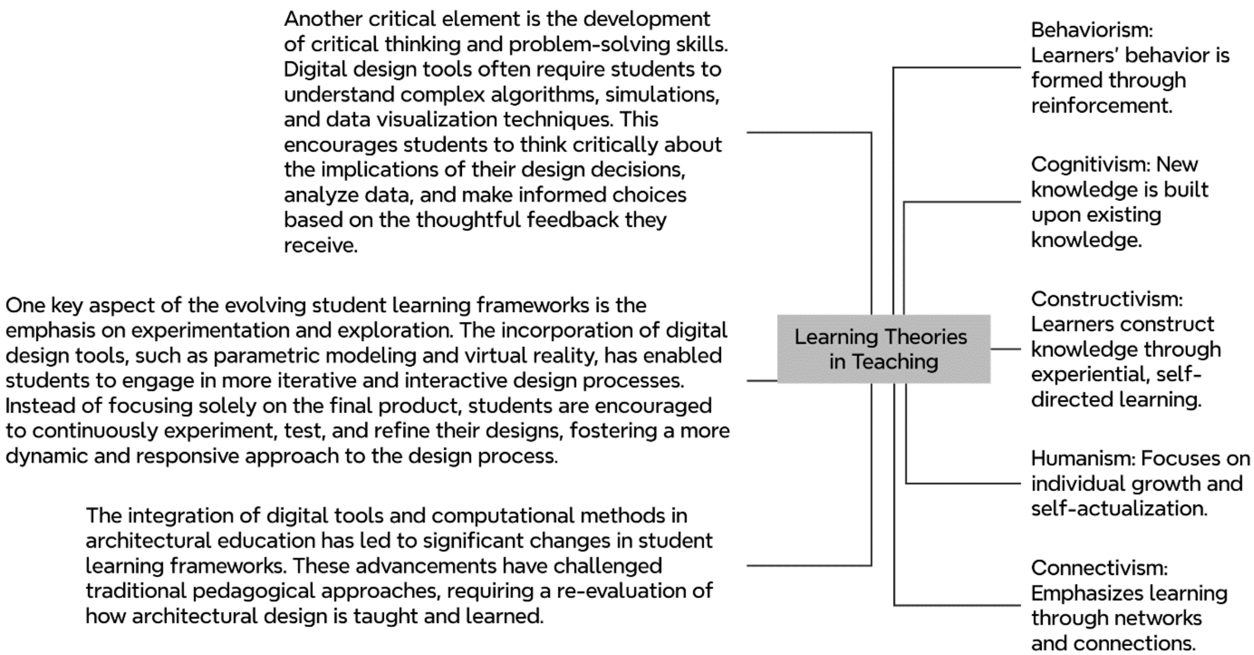

Fig1-Learning Theories in Teaching

Learning theories like Constructivism, Humanism, Connectivism, Social Learning, and Experiential Learning offer diverse approaches to engaging students and facilitating their knowledge acquisition. Constructivism fosters hands-on experiences and collaborative projects, allowing learners to construct their understanding actively. On the other hand, humanism emphasizes personal fulfillment and a student-centered approach, recognizing everyone's unique needs and aspirations. Connectivism highlights the significance of networks and technology in enhancing the learning experience, acknowledging the interconnectedness of knowledge in the digital age. Social Learning Theory underscores the importance of observation and group work, where students can learn from and with their peers. Experiential Learning, meanwhile, underlines the value of real-world experiences and reflective practices in the pursuit of knowledge and growth, empowering learners to make meaningful connections and develop deeper insights(Sediadi et al., 2022). These diverse learning theories and approaches significantly impact integrating computational methods in architectural education. Another recent study by Mamuna Iqbal (Iqbal et al., 2023) explores how students' social class shapes their learning experiences and approaches in architecture education. This study examines how architecture schools can better support students from diverse social backgrounds. The findings suggest that students with solid cultural capital and established social status tend to have more positive learning experiences, often engaging in deeper, more meaningful approaches to learning. In contrast, students with limited exposure to cultural resources and opportunities are more prone to adopting surface-level learning strategies. The quality of their early educational experiences, heavily influenced by their social class, is critical. The research argues that architecture schools should prioritize social inclusion and employ critical pedagogical approaches to foster a more constructive, empowering learning environment for students across different socioeconomic backgrounds.

This research examines Ashraf Salama's Trans critical Pedagogy, a unique and practical approach to analyzing architectural studio teaching and learning concerning a digital design studio framework. This innovative pedagogical framework, conceptualized by Salama, emphasizes the importance of critical inquiry, reflective practice, and civic engagement in architectural education. When integrating new teaching methods and digital technologies, this pedagogical technique transforms traditional design education and is closely linked to the advantages of teaching digital design to architecture students. It also helps better prepare students for contemporary professional challenges. This approach encourages students to question design theories and practices, fostering a deeper understanding of architecture's social, cultural, and environmental contexts. Students develop a more thoughtful and informed approach to their work through reflective practice. Furthermore, this student-centered pedagogy prioritizes learners' needs and interests, promoting active participation, collaboration, and a sense of ownership over the learning process. These learning attributes in the studio can be witnessed when students were taught on the Digital Studio Framework shown in Fig 6.

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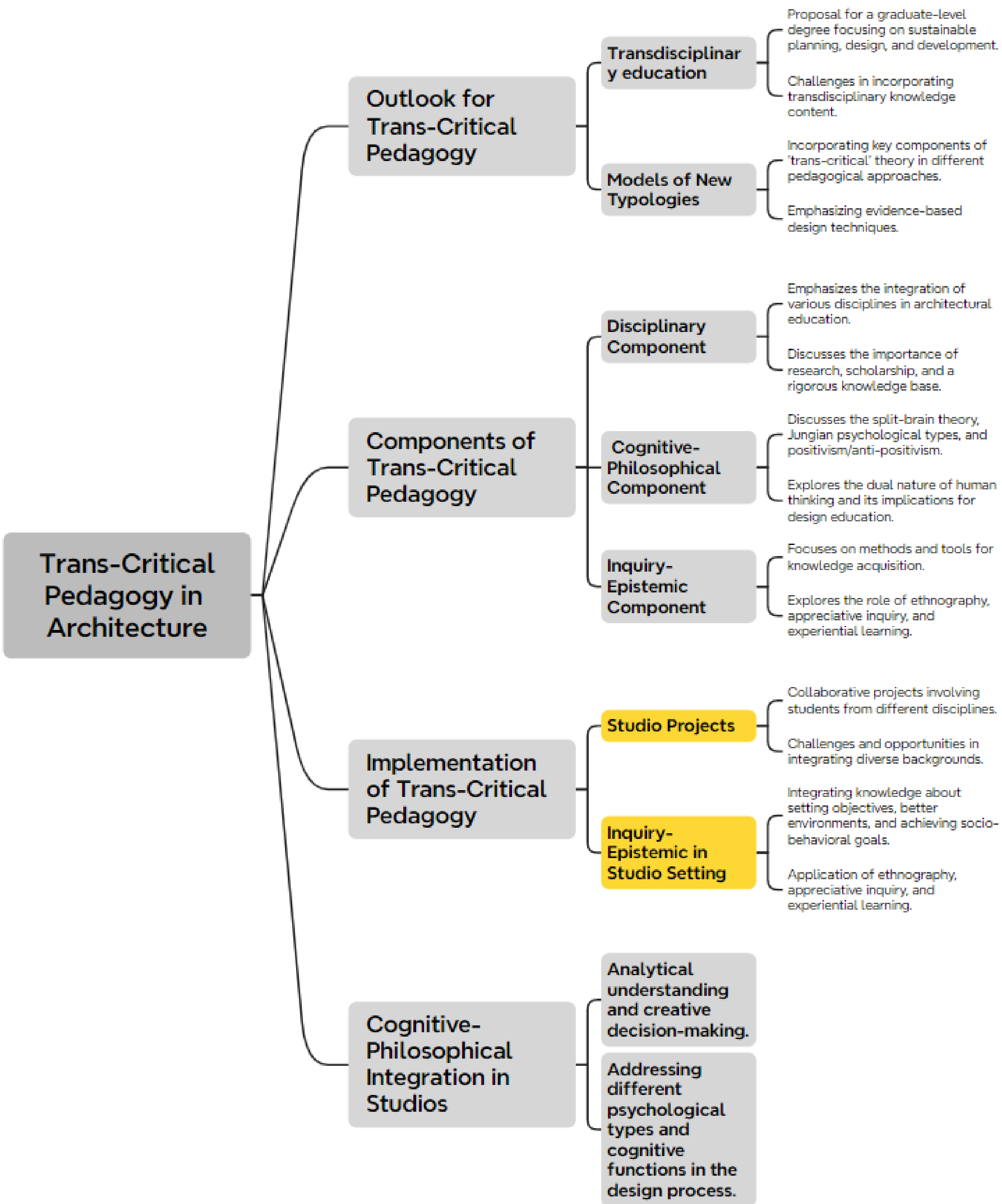

Fig 2-Trans critical Pedagogy to Enhance Student Learning in Studio by Ashraf Salama.(Salama, 1995)

Analysis of CAAD Techniques and Methodologies in Design Studios

Project I:

In this project, students used traditional design methods like manual drafting, AutoCAD, and SketchUp to create interventions for the walled city of Lahore. They aimed to revitalize the area through creative design ideas like rejuvenating handicraft bazaars and fostering place attachments. It was observed that the students came up with new and practical concepts; however, they needed more time to develop their 3D forms. Additionally, their forms were limited in dynamics, such as movable bright facades and designs responsive to real-time climatic changes.

This limitation can be addressed by incorporating computational design methods that enable the exploration of complex geometries, dynamic forms, and responsive systems. Constructivist learning theory emphasizes the learner's active role in constructing their understanding through interaction with the environment and social experiences.(Rogers & Schnabel, n.d.2022). Integrating computational tools within a constructivist framework can allow students to experiment with different design scenarios, test their ideas, and receive immediate feedback, fostering more profound engagement with the design process.(Budi Santosa, 2018).Fig 3a presents studio work done by students utilizing traditional tools. As we can see, the design concept has integrated an infinity loop, which symbolizes the interconnected nature of the community. The student wanted to convey this idea of infinite connections and relationships within the community through the infinity symbol. However, she could not fully develop the desired infinity shape due to the limitations of the SketchUp and CAD tools available to the student. Despite the technical constraints, the student skillfully modified the concept by morphing the shape to capture the essence of infinity. The student indirectly implemented an infinity loop for the design, recognizing that the number eight commonly defines the infinity symbol. The student's final shape was derived from an eight-angled geometric form to convey this conceptual element. While traditional tools posed limitations, the student recognized the inherent value of this approach. By integrating the infinity loop concept despite the software constraints, the student demonstrated creative problem-solving and a genuine dedication to their design intent. Shape modification, focusing on the essence of infinity rather than a literal representation, showcased the students' adaptability, a crucial skill for architects who often face unforeseen challenges.

By embracing the limitations of traditional tools, the student gained a deeper, more personal appreciation for the design process and the significance of conceptual thinking. This formative experience empowered the student to develop crucial architectural skills, including the ability to discover alternative solutions, adaptively overcome challenges, and cultivate creative problem-solving abilities. The student's willingness to work within the constraints of the available tools demonstrated a commitment to the design intent and a nuanced understanding of the design process, both essential qualities for successful architects who often face unforeseen obstacles in their practice.

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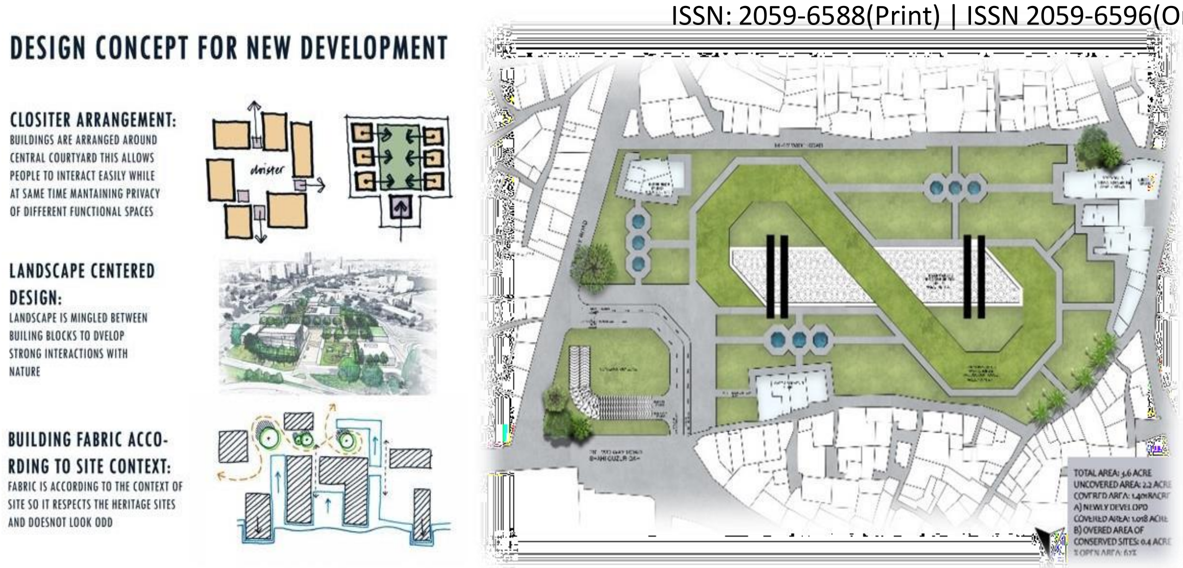

Fig 3a-Studio work of Fourth-year student

The final shape, derived from an eight-angled geometric form, reflects the student's ingenuity and commitment to honoring the symbolic meaning of the infinity symbol. Ultimately, using traditional tools can foster a more nuanced and thoughtful approach to design. To further explore the role of computational methods in architectural education, it is crucial to consider the different learning theories that can inform their integration—integrating computational methods with diverse learning approaches. As architectural education evolves, it is essential to consider how computational design methods can be effectively integrated with various learning approaches to enhance student learning and development. The exploration of computational design tools in the architecture studio context has provided valuable insights into the intersection of technology, pedagogy and student learning.

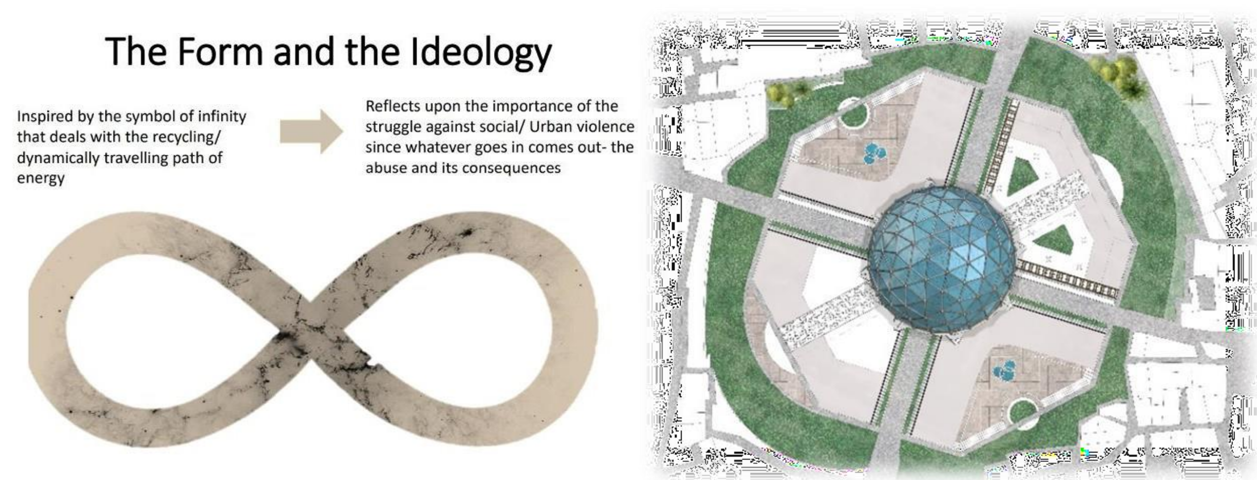

Fig 3b- Work of Student Sidra Furqan

Fig 3b presents the students' work utilizing traditional tools, such as manual drafting, AutoCAD, and SketchUp, which reflect a more linear and symmetrical aesthetic in their design projects. While they explored concepts like cloister arrangements and landscape-centric ideas, Traditional

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methods appear to limit their ability to incorporate more innovative and modern design approaches. Techniques like biomimicry or the exploration of organic forms are not apparent in their current projects. This suggests that the constraints of traditional tools may have hindered the students' ability to fully develop and express more cutting-edge, contemporary design concepts. To address this limitation, integrating computational design methods, such as parametric modeling, could give students the tools to explore a broader range of design possibilities. Parametric modeling, for example, allows students to define relationships between design elements, enabling them to generate and test multiple design iterations rapidly.

Project II- Use of CAAD in the Design Process

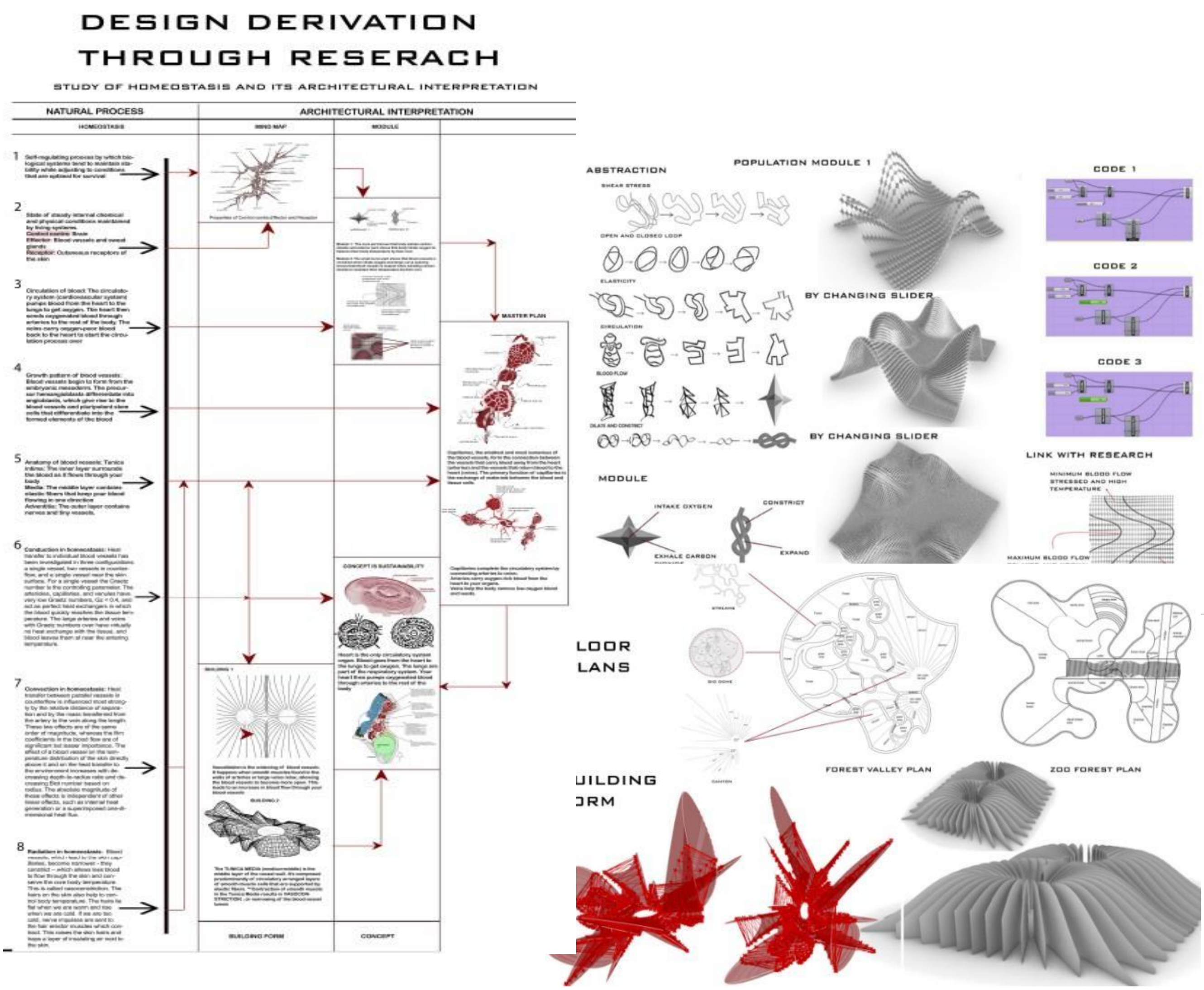

Fig 4-Studio work by fourth-year student -Laraib Raza

Cognitive learning theory emphasizes the role of mental processes, such as perception, memory, and problem-solving, in acquiring and applying knowledge (Liapi, 2001). This approach highlights the importance of providing students with opportunities to actively engage with computational tools, analyze their outputs, and develop a deeper understanding of the underlying principles and concepts. This project involves a cognitive thinking approach but could have been more accurate and contextual if computational tools had been involved.

In this project, students were introduced to digital design tools such as Grasshopper and Rhino at a very initial level. The main aim was to help them explore various tools and generate creative and new design ideas inspired by complex processes in nature or otherwise. Students incorporated unique design concepts and developed their modules through Visual Programming software like Grasshopper. They then utilized computer algorithms generated by Grasshopper to create creative meshes of their modules. This helped them develop various design forms quickly while allowing them to easily revise and change their 3D forms. The tools are efficient and accurate for the exact translation of complex problems.

The studio work of a student utilizing the computational tool has implemented the design concept of homeostasis. As can be seen, the concept is directly visible in the project. Moreover, the form utilizes a kinetic façade based on a homeostasis module, which opens and closes according to climatic conditions. Furthermore, the student can be seen experimenting with various forms before finalizing the final form. This leverage was provided by the parametric tools, which allow a single module to take various shapes according to preferred information.

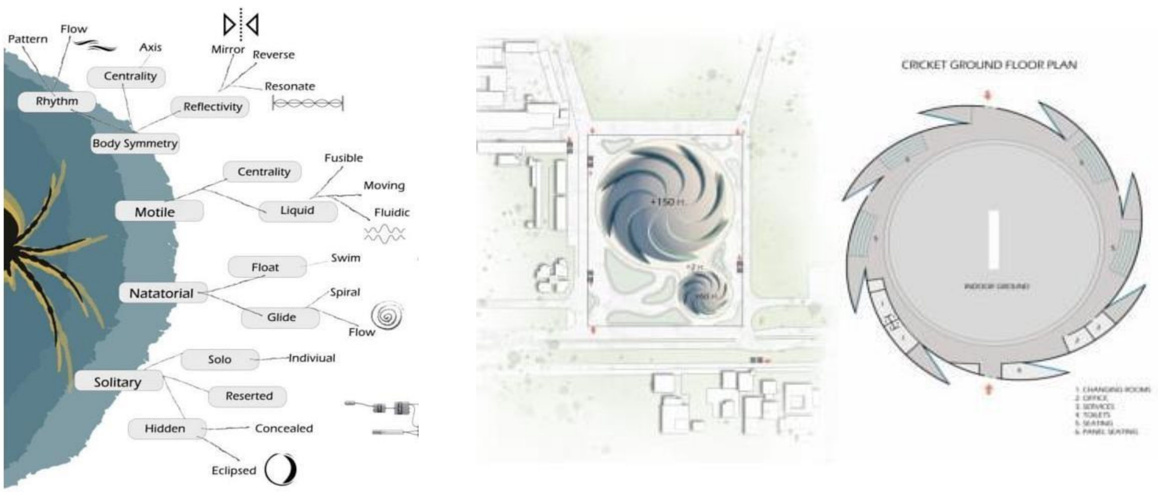

Fig 5-Studio work of 4th year Student Zoha Khalid

The framework shown in Figure 6 is a proposed Digital architecture design studio framework that emphasizes incorporating research, Digital, and computational tools for digital design. This includes exploring biomimicry, which involves examining nature's sciences and geometric patterns to inspire innovative design solutions. This framework also focuses on module design, which creates versatile, modular design components. Additionally, it covers tools like parametric, sustainability integration, and fractals to enhance the overall design process and make it more efficient and effective.

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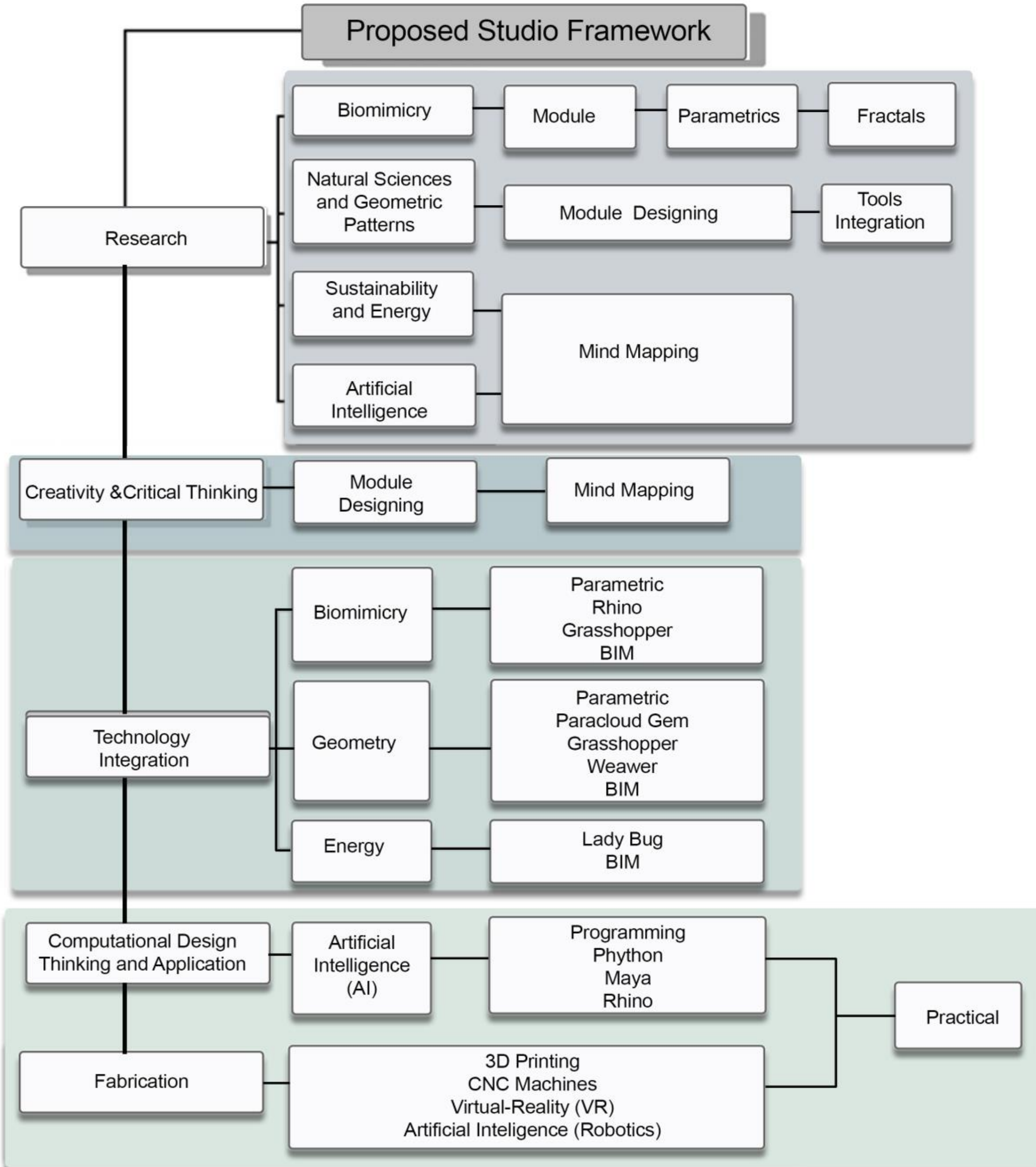

Fig 6 shows the studio Framework adopted for this studio, which was proposed at a conference in Atlanta (Perception to Execution-Design Communication Association).(Asghar & Naqvi, 2021)

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Project 2 builds on this framework, showcasing the design studio's capacity for innovative thinking and problem-solving. Exploring artificial intelligence can further enhance the creative and design processes, empowering designers to uncover new possibilities and push the boundaries of their creativity. Similarly, module design inspired by biomimicry and utilizing parametric geometry can lead to the development of versatile and adaptable design components. Software like Rhinoceros Grasshopper for parametric design also enables designers to experiment with complex geometries and intricate patterns, expanding the realm of design exploration. The "Technology Integration" stage incorporates various technologies into the design process, including tools like Ladybug Sun Path and Grasshopper BIM for interactive design, allowing students to create more dynamic and responsive architectures. This also helps focus on integrating sustainable energy solutions into the designs, creating more environmentally conscious and energy-efficient buildings.

The framework integrates computational thinking with hands-on fabrication techniques, fostering a holistic approach to digital design. It harnesses artificial intelligence for tasks like 3D printing and CNC machining while utilizing software like Rhino, Maya, and Unity VR to create physical models through 3D printing and precise computer-controlled fabrication. This interconnected system of theoretical research, practical tools, and cutting-edge technology aims to cultivate innovation and efficiency within the architecture design studio, as exemplified by the studio work presented in Fig 4. These projects embody constructivist learning theory, emphasizing the learner's active role in constructing understanding through interactive engagement with the environment and social experiences.

Integrating computational tools within a constructivist framework can allow students to experiment with different design scenarios, test their ideas, and receive immediate feedback, fostering more profound engagement with the design process. The studio process is then detailed, highlighting two significant phases: analytical understanding and creative decision-making. These phases cater to different psychological types and cognitive functions, promoting a well-rounded approach to design. The studio delves into how students navigate between analytical and creative thinking within the studio setting, offering insights into this dynamic process. Furthermore, it explores how the inquiry-epistemic component is incorporated into the studio environment. thee explores how knowledge about setting objectives, creating better environments, and achieving socio-behavioral goals is practically applied through ethnographic research, appreciative inquiry, and experiential learning. The emphasis is on the real-world application of these techniques within the studio setting.

Discussion and Analysis:

Studies of traditional design education reveal its limiting issues and constraints. The understanding of design has evolved from a simplistic view as an intuitive experience to a more complex, multifaceted investigation, reasoning, and testing process. However, the traditional approach still employs teaching techniques.

They are disconnected from the realities of design in practice. Techniques like the written program, sketch design, and finished presentation are often irrelevant to actual architectural work. Traditional architecture studios frequently focus on individualistic projects, neglecting a collaborative, group-based approach. Student performance is primarily evaluated through one-on-one interactions, reinforcing the view of architecture as an artistic expression. Students are expected to follow their instructors' guidance, rather than developing their own hands-on experiences. The traditional teaching style in architecture design studios often relies on a passive learning approach, where the instructor dictates what and how students should learn. However, a growing body of research suggests that alternative teaching methods can better support students' cognitive and learning styles, enabling them to cultivate their attitudes, aptitudes, and values. The negative consequences of using outdated educational methodologies have been extensively criticized, and several corrective models have been developed to address the evolving needs of the architectural profession.

The increasing use of digital tools and computational methods within the architecture design studio has profoundly changed how students approach and envision design. These technologies have empowered students to explore and experiment with design in novel ways, pushing the boundaries of their creativity and problem-solving skills. This research explores ways to effectively integrate digital technologies into architectural education, proposing seamless integration of these tools into design studios and developing hybrid learning models that meaningfully blend digital tools into the curriculum rather than simply adding them to existing courses. The research also emphasizes embedding digital technologies into the academic curriculum to enhance students' digital design, communication, and research skills.

Despite these advancements, the research acknowledges the current challenges in architectural education, such as the need for updated teaching methods and the ongoing debate surrounding the transformative impact of these technologies on the student experience.

The research thoughtfully examines how digital technologies can be effectively integrated into design studios, as shown in Fig 7, shedding light on the methods and challenges of this integration. While digital tools can be an efficient medium for post-production and architectural design presentations, their true power lies in their ability to empower designers and push the boundaries of creativity. Technology is advancing rapidly, offering new possibilities regarding presentation techniques, detailed drawings, and innovative design processes. Digital software like BIM, Photoshop, Sketch, and Rhino provide pre-built layouts that can be easily customized to suit the unique needs of each building project. Many architects have embraced these tools, recognizing their potential to streamline the design process and unlock new avenues for expression. Ultimately, the future of architecture may very well depend on our willingness to harness the transformative power of these digital technologies, not just as efficient tools but as catalysts for meaningful and impactful design. This research compares the conventional design work and CAAD studio methodologies, revealing how both groups successfully implemented innovative design concepts, but their final implementations differed. Students utilizing computational software were able to play with forms and structures boldly. Their work also exhibited an advanced application of energy-efficient and climate-based flexible design ideologies. Interestingly, the overall time required by both groups was similar.

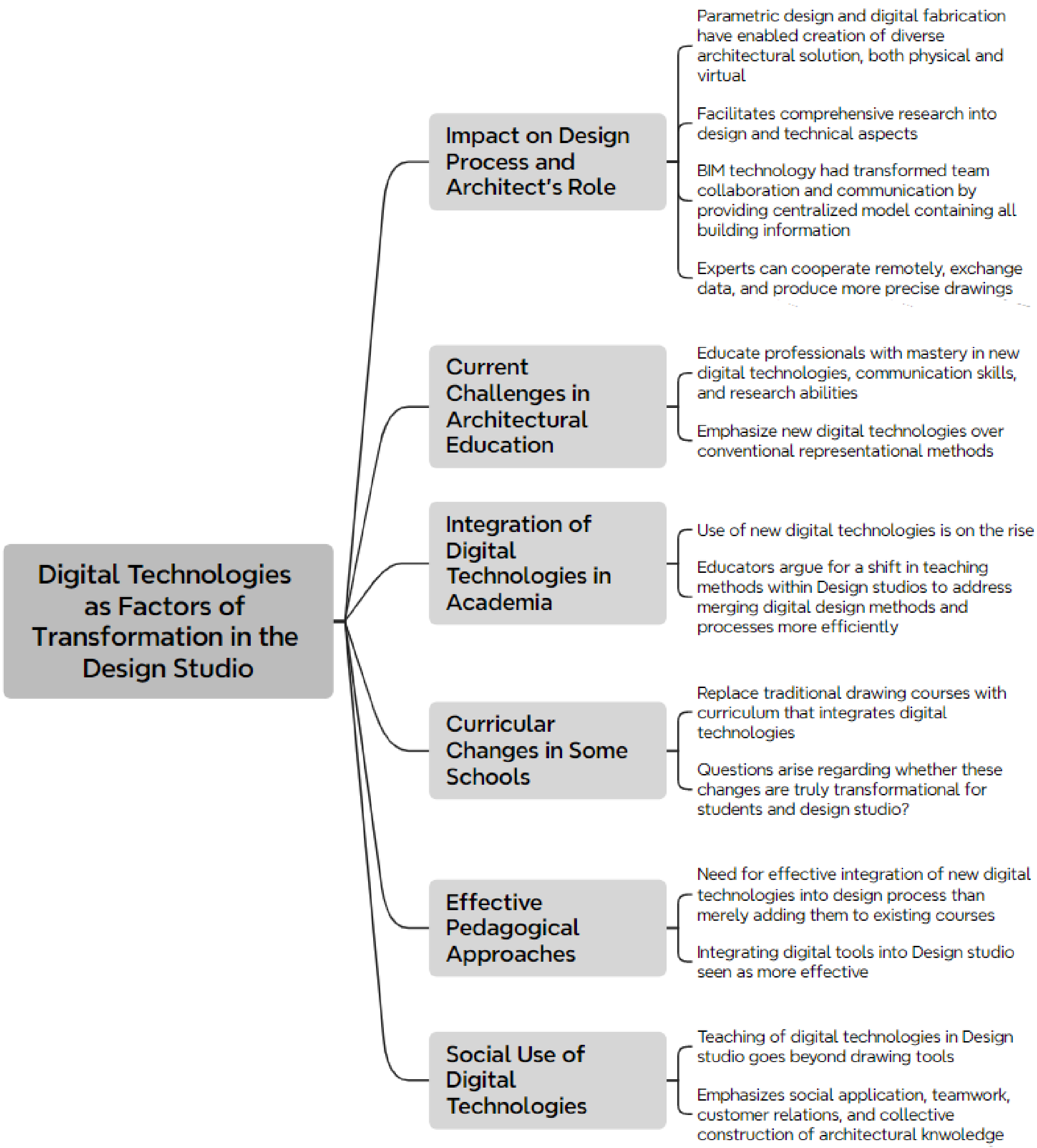

Fig7- Digital Technologies as a factor of transformation in the Design Studio

The reason was that students had to create building forms and plans manually while using traditional software. However, students using CAAD tools found it challenging to work with coding, leading to a comparable time investment for both groups. The research findings suggest that students are excited about exploring and incorporating innovative computational technologies into their design projects. They perceive these digital tools as providing more versatile design options, efficient workflows, and enhanced capabilities to express their ideas visually through advanced 3D modeling. The students view these digital tools as catalysts facilitating more accessible and time-efficient design implementation. These technologies have empowered architects and designers to express their creative thoughts and abilities more effectively.

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