Investigating Possibilities of Developing Self-Directed Learning in Architecture Students Using Design Thinking

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Abstract: Education systems are struggling to effectively integrate in their study programs the Sustainable Development Goals (SDGs) which define the challenges we need to overcome as a society in the 21st century. This study revealed the special agency that architecture and built environment have in shaping our social, economic, and natural environment using system and design thinking. Despite the several studies on the metacognitive design process, several cognitive traps still exist when developing design thinking in architecture education. This study investigated design thinking and self-directed learning in undergraduate architecture students. Responses collected from a sample of 117 undergraduates were subjected to bootstrapping in structural equation modelling to find significant relationships of reversed action when design thinking is used for developing self-directed learning. The findings suggest that design thinking is strongly connected with self-directed learning, and as shown in the resulting model, all components of self-directed learning are strongly explained by design thinking variables. This can provide insights for curriculum designers and educators on how to shape effective design thinking processes in architecture education to overcome existing shortcomings while improving interpersonal skills, creativity and digital skills, make pedagogical changes, and enhance redesign of learning outcomes towards sustainable architecture.

Keywords: sustainable development goals; design and design thinking; self-directed learning; sustainable architecture; structural equation modelling; bootstrapping

1. Introduction

The rapid changes in our social, economic, natural, and digital environment require the transformation of strategies, methods, and teaching and learning approaches to meet the sustainability needs of 21st century society. In the era of the fourth industrial revolution, the World Economic forum (WEF) has identified an urgent need for higher order thinking skills and experience, to help define high-quality and competitive education [1]. The required new characteristics are framed in Education 4.0 for the Society 5.0 framework, and are as follows: global citizenship skills, innovation and creativity skills, technology skills, interpersonal skills, personalised and self-paced learning, accessible and inclusive learning, problem-based and collaborative learning, and lifelong and student-driven learning [1]. These skills are important for the entire structure of education. Thus, the main goal of Education 4.0 is to prepare models on how to develop these Society 5.0 skills in students to create a more productive, competitive, sustainable, inclusive, and cohesive world and society [1]. The undeniable need for a diversity of knowledge and higher order thinking skills may provoke necessary changes in education systems. The education system must provide stronger support for reskilling and upskilling people both as students and afterwards as employees [2]. Consequently, any change in the education system or improvement should be done gradually and be well directed, with the key being ongoing learning [2].
Society 5.0 learner will need to be highly self-directed and the instructor more of a learning facilitator (if needed), since the learning will manifest beyond traditional educational settings and frameworks be supported and enhanced by information–communication technology (ICT), e.g., virtual, online, off-line, distance, mobile learning, transdisciplinary, and other open-ended environments [1]. The United Nations-UN [3] issued The 2030 Agenda for Sustainable Development with seventeen goals to achieve sustainable development, including the quality of work in the education system with six indicators that monitor and measure progress in primary, secondary, tertiary, and adult education. Moreover, SDGs’ implementation must pay great attention to educational interlinkages in three areas: across sectors, across societal actors, and between and among countries with different incomes [4]. Thus, Stafford-Smith et al. have proposed several actions where special focus should be on ensuring systems thinking, which can be embedded in all levels of education. ICT can support integrated global innovation systems for sustainable development of products and services [4].

Architecture education is no exception to this reconstruction of education for Society 5.0. Moreover, there is a huge, identified need for understanding the process of learning in the new era, so as to improve educational systems. Since the most desired contextual framework to architectural education appears as design, systems thinking, modelling, social interactions, and innovations with reflective practice, a need for establishing convergence and mutual action of pedagogical orientation and personal beliefs is detected [5]. Architecture students’ design projects should reflect the intentions of the designers, human centredness, and learning orientation [6], in order to meet SDGs for competitive and sustainable architecture education [7]. This fits well with the social-cognitive theory of Bandura [8], wherein students’ cognitive and personal factors and their behaviour influence each other. Moreover, the current mapping of requirements in architecture education towards SDGs shows that a wide range of knowledge, skills, and competencies will be necessary to prepare strategies for city planning, environmental design, or systems design to meet the specific design needs of a particular community, building, or home [9].

Some of the recent reports from WEF [2] have shown that new education scenarios such as the Covid-19 situation, rapid digitisation, climate change, social inequality, lack of resources, transdisciplinarity in education, and the involvement of various community and industry stakeholders, reflect the skills gaps of Society 5.0, which could be reduced by increasing the capacity for self-directed learning (SDL). SDL is a concept that appears in many 21st century learning approaches and is often seen as very important to the personal learning experience [10]. In addition, students need to be able to manage resources, demonstrate independence and use disciplined and critical thinking to solve problems. Self-directed learning can be developed during education, but the current state of self-directed learning in higher education shows deficiencies in the role of metacognition in open and flexible learning environments [5]. Moreover, self-directed learning could play a key role in transdisciplinary learning, and also in non-formal learning environments [10].

Teaching by its very nature has been seen as a process or product, and as such it reflects design science as argued by [11]. Moreover, learning as a cyclic process can be done through acquisition, inquiry, discussion, collaboration, practice, and production [11], which aligns perfectly with the design thinking process developed by Stanford university [12]. Design science as a teaching approach to architecture education is already being employed, framed in the phases of conceive, design, implement and operate, which significantly improves student skills for collaboration, creativity, and problem-solving, and affects the reflective processes in students [5–7,13–15]. Design thinking is an approach to solving some of the most complex, open-ended, and ill-defined problems in the real world [16]. It is no surprise, then, that the approach has received great attention in academic and practitioner-focused management, in all sectors of the economy [17].

Quality education is one of the United Nations (UN) 17 SDGs for 2030 [3], and it aims to ensure inclusive and quality education for all by implementing innovative and context-appropriate solutions to provide formal, non-formal, and informal education in both closed
and open contexts and also to promote lifelong learning. In this sense, the UN has defined a set of 10 objectives and 11 benchmarks. Within Education Quality Goal #4, two indicators that are part of the goal, namely 4.4 (increase the number of people with relevant skills for labour market competitiveness) and 4.7 (education for sustainable development and global citizenship) were considered relevant to the following benchmarks: 4.4.1, significantly increase the number of youth and adults with relevant ICT skills, and 4.7.1, ensure that all learners acquire the knowledge and skills needed for sustainable development. Moreover, SDL appears to be a crucial means of achieving these objectives.

Since design is central to architecture education, it would be interesting to know how the metacognitive design thinking is reflected in design practice and experiences. In this paper, we approach this emerging dilemma by bringing user-centric and sustainable perspectives together to explore ways of using a real-life framework of design thinking towards the SDL required for development of 21st century skills.

2. Literature Review

Several researchers [18–22] have identified specific skills necessary for successful and sustainable design across engineering disciplines and architecture, and these skills include the ability to (a) tolerate ambiguity through a divergent-convergent thinking process, (b) think in terms of a bigger picture, (c) handle uncertainty, (d) make decisions, (e) think as part of a team in a social process, and (f) think and communicate in several languages of design. It was also found that architecture students with a developed ability for design thinking to solve architecture problems were more likely to take it as a challenge to collect the users’ input during the problem-solving process and the solutions they generated from the users’ concerns and needs were more diverse, more imaginative, and more feasible [7,14]. It could be interesting to explore the ways of architecture design articulation, towards SDGs.

2.1. Sustainability and Architecture Education

Architecture education nowadays is no exception, in that a need for change towards a sustainable, equitable, and inclusive future for all is felt. Sustainability can be seen as “the resultant of the balanced intersection between the social, economic, and environmental dimensions” [23] (p. 3). More than ever, a professional rethink is needed about how architects cope with the aforementioned changes and challenges in varied environments to increase design and building efficacy, improve interaction between different environments and act proactively in real-life present and future situations [24]. Moreover, the interdisciplinary work of architects demands considerable skill, commitment, and creativity to optimise their creative design process [25,26]. Design-based learning might appear as regenerative learning, especially for senior students, as contemporary design education, involving the following phases: sensing, engaging (authentic involvement), learning by doing, and working with feedback and feed forward [27]; applying a social-cognitive framework is a reciprocal relationship between a person, their environment and their behaviour [8,28].

Since design is central to all majors of engineering and architecture education, it is expected that it can be taught differently, and consequently the final products of the design process will be different [29]. Moreover, generalisation of design thinking as a cognitive style across study disciplines could be harmful, and instead we must take into account designers’ practices and institutions’ characteristics, where the designer is a central focus or the main agent in designing [30]. This points to the use of a specific framework where future architects can acquire design skills and competencies to complete task or job functions. Moreover, it might be helpful if we can characterise the distinctions between freshmen and senior architecture students’ approach to engineering-design problems. Such an understanding can help shape the way architecture students practice creative design, since there is a growing interest among many educational institutions to educate and nurture competent students who will acquire labour market competitive skills and competencies [29].
An important role of architecture education and architects has been highlighted by Ramsgaard Thomsen and Miller, who provide six panels on how to integrate SDGs with sustainable architecture using design as a central activity [9]. These panels provide guidance on how to shape our social, economic, and natural environment in the way we live, interact, and build, so as to enhance sustainability through (1) design for climate adaptation, (2) design for rethinking resources, (3) design for resilient communities, (4) design for health, (5) design for inclusivity, and (6) design for partnerships of change [9]. The goals have been created and grouped—by moving from concerns of the environment, through resources, to the needs of humanity—into topics that engage existing research communities in education and industry. The mapping of the current state of the art in architectural research and industry efforts was done by 100 researchers and practitioners worldwide who are currently working to achieve the SDGs, and was analysed and elaborated by Ramsgaard Thomsen and Miller as follows:

- **Design for climate adaptation** should follow several SDGs with benchmarks on sustainable food supply and agriculture, availability, and sustainable management of water sources, sustainable and smart energy, mitigation of climate change and its impact, and sustainable use of terrestrial ecosystems, oceans, and seas. Environmental design should be supported and enhanced by technology to provide cooperative adaptation of the built environment.

- **Design for rethinking resources** examines materials we use, the methods we apply and the life cycles of products or processes. For this design, a special focus should be on sustainable consumption and production together with building resilient infrastructure, promoting inclusive and sustainable industrialisation, and fostering innovation.

- **Design for resilient communities** explores different perspectives, such as (1) economic, (2) social, (3) environmental, and also how these perspectives contribute to sustainable development of communities and urban space.

- **Design for health** deals with healthcare infrastructure, mobility, and accessibility for all, also by creation of outdoor spaces and indoor climate health and comfort.

- **Design for inclusivity** deals with egalitarian and humanitarian design, to reduce poverty, ensure quality education, and reduce inequalities within and between societies and countries.

- **Design for partnership of change** challenges the boundaries of architectural design and examines how architecture and the built environment can encourage such partnerships, where architecture can be an important driver for change [9].

The architecture education for SDGs reflects the five characteristics of design projects: (1) sustainability could be perceived as an emergent property of design thinking through reflection-in-action (2), a global approach that is beyond the sum of its objectives, (3) a singular approach that seeks original responses to specific situations, (4) a tool for dealing with complexity and uncertainty, and (5) systems thinking in the context of an open system that allows for modifications [9,23].

In a complex higher education environment, the need for pedagogical change and technological innovation toward SDGs cannot be overlooked [31–33]. Students at the end of their studies face the possibility of having to wait for industries or job roles to evolve that do not yet exist [34]. Institutions provide education for increasingly fragmented and complex markets that require different learning outcomes, implementation modalities and flexible approaches to learning [35], whereas governments are expected to regulate higher education and provide quality practices and funding to reflect socioeconomic policies [36].

Many authors cite the functions, activities, and aspirations of the modern university in the digital age [31,37–39]. Many of these studies also cite changes from critical engagement with curriculum design and modelling to the reliance of teaching and learning practices on ICT and the influence of social media and other social networks. These claims about the disruptions attributed to ICT and the need to adapt and change education in recent times are not a new phenomenon, but date back several decades, since the advent of computing and the first computers. Challenges regarding the effectiveness of implementing
strategic pedagogical change through ICT have created binary positions and opposition, in which ICT has been referred to as both the enemy of good teaching and, contrarily, as a powerful tool for improving learners’ skills [31,40]. Pedagogical change and the thoughtful instructional use of ICT can be important tools in ensuring that institutions are competitive in a modern higher education environment. They support both improved practice and opportunities for innovation. The advanced use of ICT can be an important tool and reason for a modern higher education institution operating successfully in the digital Society 5.0, which is being shaped and transformed by ICT, artificial intelligence, and interoperability of stakeholders, processes, and systems [41]. Moreover, with intelligent and purposeful integration in the teaching and learning process, the level of different competencies of students, including innovation competence, can be significantly increased [41,42].

Identifying the factors of architecture education for sustainable development in undergraduates is an important area that we are currently paying more attention to due to this being the early stage and due to its still infrequent use in higher education. Although ICT in education is developing and changing rapidly, the use of artificial intelligence in long-term learning planning can be very important to promote development according to various criteria and indicators of education for sustainable development. Since the design thinking for sustainable architecture is undertheorized, there is an immediate need for more critical thinking on the issue [30].

Critical thinking and problem-solving skills, creativity, communication, and collaboration skills, and character traits such as curiosity, initiative, perseverance, adaptability, leadership, and social responsibility, are necessary for innovative education and can be developed during training and later [43]. This suggests that training institutions for future architects should balance study programs to enable the acquisition of different types of knowledge in areas relevant to future architects (subject matter, pedagogical content knowledge, technological pedagogical content knowledge), including new knowledge from different disciplines and educational sciences [44].

It is important for future architects to acquire sophisticated generic competencies during their studies, which will enable them to develop the ability to transfer, modify, redefine, and foster new learning approaches and methods [43]. In this way, future architects can work more effectively and be more motivated and creative and develop a positive attitude towards SDGs while actively participating in the creative, social, and community environment. It enables the use and development of their metacognitive and interpersonal skills and systems thinking [45].

The role of design in architecture education has been recognised in Poland in the context of the education standards for the architectural profession; the very last regulation came into force in 2019 [46]. For institutions to meet these standards, they must understand design and the manner in which students learn design. Due to the significant importance and necessity of design, a new curriculum for architecture also involves the concept of design in the first Bologna cycle [46], while the previous curriculum had the majority of the design topics in the second Bologna cycle. Design is conceptualised as architectural and urban with several contexts, e.g., landscape architecture, heritage conservation, culture studies, environmental protection and ecology, as well as ergonomics. Engineering and technology is taught as construction and materials science, statics and structural mechanics, building physics, building services, and building structural systems and urban infrastructure. The design toolset presents drawing, painting, computer-aided design, modelling, mathematics, and geometry. Design in the second Bologna cycle involves more creativity and the use of different techniques and methods of creative thinking to increase effectiveness of design for innovation learning [46]. Moreover, teachers of design subject matter are struggling to integrate SDGs in their curriculum or in the projects they run with students in different areas to provide sustainable architecture design [6,14]. A complex and systemic manner of SDGs’ integration into the architectural design curriculum can offer students “(1) a platform to build up the buildings’ occupants’ awareness of the impact of their behavioural attitudes and habits on the natural environment, as well as on the
building's environmental performance; (2) a model for shaping components recognized as determinants of the buildings' users' environmentally responsible conduct; (3) a learning tool to gain the ability to implement creative, innovative, and evidence-based sustainability issues into design projects” [14] (p.16). It may also be helpful in decision making on ecological utilisation, and boost effectiveness of the management models [6].

Based on these findings, a humanist approach, focused on pedagogical change and innovation, was found to be the most appropriate for developing meta-cognitive design thinking for integrating the SDGs in design for sustainability. Thus, we contribute to science by providing more evidence on how to articulate design thinking, consequently offering more insights into measurement of design thinking itself to overcome the difficulties faced so far in measuring results in ways that are meaningful to the discipline or organisation [17].

2.2. Self-Directed Learning and Design Thinking

Metacognitive skills play a central role in students' learning performance, especially where an amount of procedural knowledge is demanded to solve a task or assignment [41]. Architecture students during complex design tasks exploit the reflective process to use the design knowledge and decision-making ability and apply metacognitive strategy to alter learning according their processing or interest in learning [5]. Considering the reflective process in learning, Brookfield offers a definition of self-directed learning as:

“Self-directed learning is learning in which the conceptualization, design, conduct and evaluation of a learning project are directed by the learner. Learners can work in self-directed ways while engaged in group-learning settings, provided that this is a choice they have made believing it to be conducive to their learning efforts” [47] (p. 2615).

Regarding the definition, when students are engaged in real-world design tasks, they are more aware of and attentive to their thinking process, prefer goal orientation in their performance and they can impose learning strategies they need to enhance the design process and improve design outcomes [5]. Moreover, the instructor or educator should develop educational activities where metacognitive components such as higher order thinking skills can be utilised and developed within the design course [48]. On the other hand, design education requires a metacognitive approach to developing creative processes that can be made tangible for the designers, reflecting previous experience and knowledge and thus giving the designer the ability to solve any particular design challenge [49,50]. Thus, design thinking employed in the design process can be seen as a cyclic process where the cycles are dynamic, complementary, and allow focus and content shift in order to complete and master the tasks [12,51].

A perspective of design thinking used in this study followed articulation provided by Stanford University researchers [12], who saw it as: (1) empathy, (2) definition, (3) ideation, (4) prototype, and (5) testing of solutions. Moreover, design thinking, which is framed within creativity, empathy, and rationality can enhance problem- or solution-driven design tasks, and it also depends upon critical thinking and decision-making ability as a complement to creativity [52]. Design thinking can be used either in classroom settings or beyond, e. g., distance learning, online, offline, or blended learning using different approaches, methods, and strategies in each single phase of design thinking that enables students’ transfer of team learning. Employing different stakeholders or the content of different disciplines in design tasks can result in new knowledge and skills, especially creativity, innovativeness, digital skills, interpersonal skills, and creative self-efficacy and design flow experience [53,54]. Design thinking shows values such as practicality, ingenuity, empathy, and appropriateness as well as values rooted in humanity, e.g., subjectivity, imagination, commitment, and justice [55,56], as human-centred design is socially situated in values and sense making [56,57]. Moreover, it was argued by [7,56] that design thinking can make a change towards SDGs and sustainable architecture, and it may provoke the use of different strategies and methods as a part of self-directed learning to develop innovativeness, creativity and digital skills.
An engineering view on design describes it as a “systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints” [22] (p. 104), and as an educational approach, design and design thinking have been selectively applied to engineering and architecture curricula over a wide range of disciplines [54].

A complex perspective of design was presented by Dorst, where abduction leads to most creative and innovative designs [51], also towards SDGs [9]. So-called productive design utilises abduction when a designer knows only a value (aspired) which users need, while the thing (what) and working principle (how) are unknown [51]. Designers cope with the probability of solution or design realisation when the rule is set, while result and example are very often subject to a trade-off in an extensive decision-making process. This points to a higher level of student motivation, productivity, and engagement if they want to address complex design tasks, and shapes innovative behaviour needed for sustainable architecture [14]. An affective commitment and intrinsic motivation can be the key to success in the design-based activities of architecture students. It might be that using a self-determination theory we can explain what underlies the productive and satisfying learning experiences of user-centred design tasks, as Ryan and Deci [58] have argued.

The inclusion of metacognition in design tasks is well supported by a myriad of authors [5,7,56,59,60], but as they have reported, several cognitive pitfalls can occur, especially for unwary designers, if internal thought processes are not well understood and used [60]. The shortcomings or failures have been seen as a result of top-down processing, which can lead to encoding failures, inattentional blindness, confirmation bias, cognitive fixation, among other things [60]. In order to provide more insights on metacognitive design thinking and to overcome these cognitive traps, we decided to investigate the opposite process, also supported by the social cognitive theory of [8], where self-regulation shapes and is shaped by the environment and by personal factors such as cognition, affective states, and self-efficacy. The conceptual framework of this study is depicted in Figure 1.

SDL may appear as a cyclic process [61], where learning begins with students’ assessment of learning challenges when, based on their own current knowledge, skills, and attitudes towards the subject, students determine an appropriate learning objective. Strategic planning and learning strategy can lead to optimisation of learning, where students must choose effective learning strategies to help them achieve the objective they have set. In the next step of the cycle, the strategic implementation of planned learning is carried out, followed by students’ strategic monitoring and reflection on their own progress. If
required, a strategy adjustment can be done, while the first level of the cycle ends with evaluation of the learning outcome. The next cycle may occur at any level of knowledge, skills, and competence acquisition [61].

We have assumed that design thinking, as the non-linear and iterative process involved in design activity, can be framed by creativity, empathy, and rationality which can be deployed in real-world contexts of architecture design. Moreover, abductive thinking, learning orientation, mindfulness, and awareness of process, embracing risk, collaboration and teamwork, openness, and problem reframing might have predictive value in students’ SDL.

For the purpose of the study, the following research questions (RQs) were addressed:

- **RQ1**: What are the characteristics of design thinking in undergraduate architecture students?
- **RQ2**: What are the characteristics of self-directed learning in undergraduate architecture students?
- **RQ3**: What is the relationship between architecture students’ design thinking and their self-directed behaviour?

### 3. Materials and Methods

A quantitative approach was used in this empirical study. In particular, a survey was conducted to understand the design thinking in architecture education and to provide an underlying structure of SDL for sustainable architecture.

#### 3.1. Sample

The study sample consisted of 117 undergraduate students from the Cracow University of Technology, Poland during the academic year 2020–2021. The sample included more females \((n = 100, 85.5\%)\) than males \((n = 17, 14.5\%).\) The numbers of students in their first, second and third year of study were 47, 32, and 38, respectively. The students were informed of the purpose of the study. Participation in this research was completely voluntary, and an informed consent form was presented clearly to the students, including safeguards for privacy which were needed to protect the privacy and interests of the participating students. When all possible questions from the students had been answered to their satisfaction, they signed the consent form, agreeing to the research. Moreover, students were also informed that their participation/non-participation in the research would have no impact on their grade. Students were free to withdraw from the study at any stage.

This study involved participation of 117 undergraduate students of architecture, with an average age of 20.32 years. The participants were predominately female (100 out of 117, 85.5%).

#### 3.2. Instruments

##### 3.2.1. Design Thinking

Design thinking in architecture students was assessed using Dosi et al.’s [62] questionnaire with a 6-point Likert scale (from 6 = strongly agree to 1 = strongly disagree), adapted by the authors of the present study. Design thinking can be seen as a complex construct which includes creativity, cognition, metacognition, attitudes, and skills. Dosi et al. created an instrument which can cope with different challenges in the design thinking process, such as implementation variants, measurement of possible approximations of design thinking derived from practices, and inclusion of several types of feedback and customers’ satisfaction [62]. Moreover, the questionnaire can be suitable, given the nature of sustainable architecture, towards SDGs’ achievement in different open-ended and trans-disciplinary learning environments, too.

The design thinking mindset explained in detail by Dosi et al. consists of 19 constructs with 71 items [62]. An original questionnaire has a 5-point Likert scale while we used a 6-point Likert scale. We have chosen this scale because the ultimate purpose of the instrument was to track development of metacognitive awareness for purposes of either
self-assessment or research. Moreover, the 6-point Likert scale since it has an even number of ratings on the scale, obligates respondents to choose the positive or negative end of the scale, resulting in better data. Furthermore, if at any point neutral is desired, then the “slightly agree” and “slightly disagree” can be averaged together [63–65].

The design thinking questionnaire’s items were divided on the following 19 constructs:

1. **Ambiguity and uncertainty tolerance.** To be comfortable with ambiguity is to be accustomed to leaving doors open as long as possible, to view a solution as an imprecise concept and often inconclusive, to engage in a process where the outcome, the amount of iteration, and the time it will take to achieve the result are unknown [62].

2. **Embracing risk.** Risk-taking involves the risk of failure and failing fast, and the propensity to take risks with respect to process that allow for deep exploration of context and new solutions. Designers are aware of exploring and expanding design knowledge and cannot disregard or ignore risk taking [62].

3. **Human centeredness.** Being people-centred means focusing on understanding human behaviours, needs, and values, as a way to solve complex and strategic problems. Being user-centric is not about asking customers what they want; rather, it is about finding out what they need [62].

4. **Empathy.** Empathy is the foundation of a human-centred design process. It is the ability to see things from multiple perspectives, to create customer intimacy, is the ability to see and experience through another person’s eyes, to see why people do what they do. Being empathetic is being open, non-judgmental, and comfortable with people from different backgrounds and opinions [62].

5. **Mindfulness and awareness of process.** Design Thinkers are aware of the process in the sense that they know where they are in the design process, whether they are in a converging or diverging phase, whether they need to be highly generative versus when it is necessary to converge on a single solution path [62].

6. **Holistic view/consider the problem as a whole.** This is the ability to look at the whole problem, taking into account many factors, e.g., socio-economic patterns, relationships, interdependencies, including customer needs, technical feasibility, organizational constraints, regulatory impact, competitive forces, availability of resources, and costs and benefits of different proposed solutions [62].

7. **Problem reframing.** Problem reframing means to reformulate the initial problem in a meaningful and holistic way, to expand the problem, to question it, to take in all the findings and to find a correct interpretation [62].

8. **Team working.** Design Thinkers need to collaborate, share their knowledge, discuss with visualization tools to better communicate and clarify what they are up to. Teamwork is about sharing and developing knowledge together and supporting other team members [62].

9. **Multi-/inter-/cross-disciplinary collaboration.** Collaboration is essential to design thinking and each Design Thinker must work in a multidisciplinary team with others from different backgrounds, perceptions, and perspectives, or collaborate with individuals from other organisations [62].

10. **Open to different perspectives/diversity.** Diversity can be understood to include working together in different teams and integrating different outside perspectives into the process [62].

11. **Learning oriented.** Learning orientation is an essential feature of Design Thinkers. Design thinkers have an appetite for learning, a desire to learn, even about others, to question existing frameworks and to seek new contexts in which to learn. Their main source of learning is action: learning by doing through observation, rapid prototyping, and hypothesis formulation [62].

12. **Experimentation or learn from mistake or from failure.** Design Thinkers dare to experiment with failure because, due to its ambiguity, failure is seen as an opportunity to discover new possibilities, an opportunity to learn. Failure is not seen as a waste of time, but is actually encouraged. Experimentation can be seen as a tendency to test and try
things out in an iterative way and to switch between divergent and convergent ways of thinking [62].

13. Experiential intelligence / Bias toward action. Design thinkers are characterised by the Experiential Intelligence: the ability to make tangible, to bring to life what is not, to understand and activate all five human senses to make innovation tangible, known, and alive, to transform concepts generated in the what-if phase into feasible, testable models, to favour action-oriented behaviour over discussion and conceptual or analytical behaviour [62].

14. Critical questioning. It is the exercise of questioning everything, is the ability to ask the right question, to keep an open mind to possibilities, to have a beginner’s mind that goes to the source of the problem, avoiding losing sight of the goal [62].

15. Abductive thinking. It is the logic of what could be, it is moving from the known to the exploration of alternative solutions, the generation of new ideas. It is the ability to be future-oriented, to draw conclusions from incomplete information, to make small leaps into a partially known future [62].

16. Envisioning new things. It is the ability to make ideas tangible, to imagine possibilities thanks to the use of drawings and mock-ups and to bring them to life. It involves the ability to “see” the end result as a concrete and complete picture: to “see” the complete solution in its most robust form, to “see” the way the company will work with all the necessary partners and enterprise systems, and even to “see” the success in the market and the potential paradigm shift that a breakthrough can trigger [62].

17. Creative confidence. Creativity is a mental activity, but it can also be part of a system model; it is the ability to think differently, to challenge traditional processes and styles. Creativity is critical to design thinking as a mode of exploring and expressing less tangible and more subjective content by bringing the abstract or non-experiential to life. Creative confidence is demonstrated by tackling problems that you would rather know what you don’t know than what you do know, and it relates to your confidence in your own creative problem-solving abilities [62].

18. Desire to make a difference. Design thinking professionals have the desire and are therefore determined to make a difference, by, for example, creating something visual that breaks through, or they are inclined to turn a discussion into a strategic intent. They have a desire to develop the skills, structures, and processes to generate value from valuable insights, and they are determined to convince someone of their idea and justify it if they find it valuable [62].

19. Optimism to have an impact. Optimism can be seen as the state of mind of design thinking teams. It is the ability to move forward, knowing they will not always be right, but optimistic about their ability to experiment and course correct as they go along [62].

3.2.2. Self-Directed Learning

A number of scales have been proposed to measure self-directed learning, as outlined by Litzinger et al. [66], Saks and Leijen [67], Ziegler [61], and Cadorin et al. [68]. However, considering the above characteristics of sustainable architecture design integrated with SDGs, Williamson’s self-rating scale of self-directed learning (SRSSDL) seems most appropriate to detect the skills required for undergraduate architecture students [69].

The SRSSDL questionnaire was used to survey students’ perception of their ability for self-directed learning. This scale features 60 items in five subscales with 12 items each:

20. Awareness. Learners’ understanding of the factors that contribute to becoming self-directed learners. This subscale is designed to identify how learners are able to identify learning needs, select the best method for their own learning, maintain self-motivation, be responsible for their own learning, and identify their own deficits.

21. Learning strategies. The various strategies that self-directed learners should adopt in order to become self-directed in their learning process. These strategies are related to active learning combined with a student-centred approach.
22. **Learning activities.** The required learning activities that learners should actively engage in to become self-directed learners. Different learning styles can be revealed along with students’ level of technological pedagogical content knowledge.

23. **Evaluation.** Learners’ need certain qualities to monitor and manage their learning activities. Critical thinking and decision making are particularly important skills to enhance learning, while self-efficacy can be strengthened by observing others at work.

24. **Interpersonal skills.** Skills of learners in interpersonal relationships, which are the prerequisite for them to become self-directed learners. In addition, the ability to transfer team learning may be revealed when learners are engaged in a variety of challenging tasks. The openness and ability for different interactions in design work or experimentation can promote SDL [69].

Responses for each item were rated on a 5-point Likert scale (5 = always, 4 = often, 3 = sometimes, 2 = seldom, 1 = never). The questionnaire provides a measure of the self-directed learning level according to the following criteria by Williamson [69]. The maximum score is 300 points. A range from 60 to 140 points represents a low level of self-directed learning; from 141 to 220 represents a moderate level of self-directed learning; 221 to 300 represents a high level of self-directed learning. Internal consistency was measured with the Cronbach’s alpha coefficient for the total scale and the subscales, considering the acceptable values suggested by [70], which should be greater than 0.70.

3.3. **Procedure and Data Analysis**

Both questionnaires were distributed online to the architecture students’ email addresses, where a link to the questionnaires was provided. Students participated in the study during online distance learning sessions at the end of October and the beginning of November 2020 throughout a study day, and they were briefed about the research and ethical considerations, before completing the questionnaires and validation tasks in an e-classroom through MS Teams and the Zoom platform.

The data were analysed with The Social Sciences Statistical Package IBM SPSS (v.25) software. Cronbach’s alpha coefficient was used to support the reliability of the tests. Besides this, there were the basic tools of descriptive statistics to present the students’ basic information, and the mean score, and standard deviations of dependent variables. Given the lack of adjustment to statistical normality, due to ordinal nature of the variables, non-parametric contrast tests were used: Friedman (for repeated measures) and Kruskal-Wallis (when more than two groups are compared). The effect size was estimated on the epsilon square scale, as proposed by [71]. Due to relatively small sample size $n = 117$ and no multivariate normality where critical ratio was calculated of 3157 which is greater than the acceptable ratio of 1.96 [72], the bootstrapping procedure in structural equation modelling (SEM) was used to evaluate the metacognitive design thinking model. IBM SPSS Amos (v.24) software program was used to fit SEM.

4. **Results**

4.1. **Perceived Ability for Design Thinking**

Students’ design thinking ability was assessed on a 6-point Likert scale against 19 subscales of the questionnaire. Figure 2 shows their average scores expressed with a mean, where an equal distance was assumed between ordinal values on the scale.

Students, in general, have evaluated themselves above the average on all subscales of design thinking. A mean value of 5 was exceeded on subscales of (a) Empathy, (b) Problem reframing, (c) Multi-/inter-/cross-disciplinary collaborative teams, (d) Open to different perspectives/diversity, (e) Learning oriented, and (f) Desire to make a difference. It seems that architecture students are more empathic than average, which is reflected in a greater experiential orientation, capability of problem reframing (which indicates their well-developed ability to define or redefine problems in order to find the best solutions to design problems), and capability of collaboration and transdisciplinary learning (which is especially important when heterogeneous teams are engaged in transferring team learning using
cognitive variation of tasks or assignments). In addition, architecture students possess a wide range of interpersonal skills, which are necessary for superior results, and have a strong desire to make a difference by creating something visual or strategically sound to generate value from valuable insights. Their ability to be learning-oriented allows them to reflect on process knowledge, and control and monitor their own pace of learning.

The mean values of those who had answered the complete set of items \((n = 117)\) were contrasted, which vary in the range between 1 and 6 points. The differences observed between these items are significant, with \(p < 0.001\) (Friedman test: Chi-square value = 390.41; \(p = 0.000\); moderate effect size: Kendall’s \(W = 0.324\)). For Kendall’s \(W\) effect size, the interpretation guidelines of 0.1 (small effect), 0.3 (moderate effect), and above 0.5 as a strong effect were used [70]. The differences between different constructs of design thinking were calculated in order to find out whether the constructs are evenly developed among students or some constructs are underdeveloped compared to others. Thus, we found significant differences \((p < 0.05)\) using a Wilcoxon rank test between: (1) Embracing risk and Ambiguity and uncertainty tolerance against all other constructs of design thinking. (2) Mindfulness and awareness of process and all other constructs of design thinking. (3) Abductive thinking and almost all others excluded Human centeredness, Team working, Experimentation or learn from mistake or from failure and Creative confidence. (4) Envisioning new things and Embracing risk, Ambiguity and uncertainty tolerance, Empathy, Mindfulness and awareness of process, Problem reframing, Multi-/inter-/cross-disciplinary collaboration, Open to different perspectives/diversity, Learning oriented, Desire to make a difference, Creative confidence, Abductive thinking.

This test revealed five different development levels of design thinking ability in students as follows, from 1-less developed constructs to 5-higher developed constructs:

1. Ambiguity and uncertainty tolerance, Embracing risk.
2. Mindfulness and awareness of process.
3. Abductive thinking, Creative confidence, Human centeredness, Team working, Experimentation or learn from mistake or from failure/.
4. Optimism to have an impact, Holistic view/consider the problem as a whole, Envisioning new things, Experiential intelligence/Bias toward action, Critical questioning.
5. Empathy, Open to different perspectives/diversity, Desire to make a difference, Problem reframing, Learning oriented, Multi-/inter-/cross-disciplinary collaborative teams.

Figure 2. Students’ perceived ability for design thinking on 19 subscales with a mid-point score of 3.5 and 95% confidence intervals.
Students’ average scores across the study year and in total are shown in Table 1. Average scores are expressed with a mean (M) and standard deviation (SD). The questionnaire in the present research proved to be moderate to highly reliable, with Cronbach’s α values of the constructs between 0.70 to 0.92. Cronbach’s alpha coefficient values, based on the sample of this study, are also shown in Table 1.

Table 1. Students’ average scores on design thinking across the study year, and Cronbach’s α on design thinking questionnaire’s subscales.

| Subscale                                                   | First-Year Students | Second-Year Students | Third-Year Students | Cronbach’s α |
|------------------------------------------------------------|---------------------|----------------------|---------------------|--------------|
|                                                            | M       | SD     | M       | SD     | M       | SD     |                |
| Ambiguity and uncertainty tolerance                        | 3.60    | 0.70   | 3.52    | 0.70   | 4.13    | 0.75   | 0.75            |
| Embracing risk                                             | 3.34    | 1.11   | 4.00    | 1.01   | 4.11    | 0.81   | 0.89            |
| Human centeredness                                        | 4.43    | 0.98   | 4.96    | 0.46   | 5.00    | 0.65   | 0.81            |
| Empathy                                                   | 4.85    | 0.90   | 5.20    | 0.68   | 5.31    | 0.64   | 0.92            |
| Mindfulness and awareness of process                      | 4.09    | 0.78   | 4.55    | 0.62   | 4.63    | 0.56   | 0.74            |
| Holistic view/consider the problem as a whole             | 4.63    | 0.71   | 4.90    | 0.58   | 5.21    | 0.63   | 0.73            |
| Problem reframing                                         | 5.03    | 0.72   | 5.33    | 0.86   | 5.61    | 0.42   | 0.81            |
| Team working                                              | 4.58    | 0.71   | 4.87    | 0.54   | 4.83    | 0.66   | 0.72            |
| Multi-/inter-/cross- disciplinary collaboration            | 5.21    | 0.64   | 5.55    | 0.46   | 5.22    | 0.76   | 0.78            |
| Open to different perspectives/diversity                  | 4.89    | 0.72   | 5.20    | 0.42   | 5.33    | 0.58   | 0.70            |
| Learning oriented                                         | 5.02    | 0.62   | 5.55    | 0.43   | 5.42    | 0.70   | 0.82            |
| Experimentation or learn from mistake or from failure      | 4.54    | 0.80   | 5.08    | 0.68   | 4.82    | 0.91   | 0.87            |
| Experiential intelligence/Bias toward action              | 4.77    | 0.52   | 4.97    | 0.60   | 5.09    | 0.52   | 0.73            |
| Critical questioning                                      | 4.71    | 0.90   | 5.14    | 0.66   | 5.36    | 0.76   | 0.82            |
| Abductive thinking                                        | 4.40    | 0.75   | 4.62    | 0.74   | 4.96    | 0.55   | 0.81            |
| Envisioning new things                                     | 4.67    | 0.78   | 5.03    | 0.77   | 5.05    | 0.59   | 0.78            |
| Creative confidence                                       | 4.30    | 0.89   | 4.92    | 0.94   | 5.18    | 0.63   | 0.90            |
| Desire to make a difference                               | 4.90    | 0.74   | 5.06    | 0.78   | 5.54    | 0.45   | 0.71            |
| Optimism to have an impact                                | 4.46    | 0.88   | 5.54    | 0.55   | 5.16    | 0.78   | 0.86            |
| Total score                                               | 4.55    | 0.54   | 4.94    | 0.65   | 5.05    | 0.63   | 0.94            |

Students’ average scores on the subscale items are contrasted (using non-parametric tests) based on study year group as the differentiating factor. To find the differences between the group of students with respect to their ability for design thinking across its subscales, a Kruskal-Wallis test was used with a Dunn-Bonferroni post hoc test. After Dunn-Bonferroni corrections we found significant differences for subscales of (1) Holistic view/consider the problem as a whole between students in study years 3 and 1 (H = 15.238, p = 0.025, relatively strong effect size epsilon square = 0.23), (2) Problem reframing between students in study years 3 and 1 (H = 15.638, p = 0.020, relatively strong effect size epsilon square = 0.24), (3) Open to different perspectives/diversity between students in study years 3 and 1 (H = 15.638, p = 0.020, relatively strong effect size epsilon square = 0.22), (4) Learning oriented between students in study years 3 and 1 (H = 16.264, p = 0.035, relatively strong effect size epsilon square = 0.25), (5) Critical questioning between students in study years 3 and 1 (H = 15.195, p = 0.026, relatively strong effect size epsilon square = 0.23), (6) Abductive Thinking between students in study years 3 and 1 (H = 15.267, p = 0.026, relatively strong effect size epsilon square = 0.23), (7) Creative confidence between students in study years 3 and 1 (H = 19.617, p = 0.002, relatively strong effect size epsilon square = 0.30), (8) Desire to make a difference between students in study years 3 and 1 (H = 17.348, p = 0.008, relatively strong effect size epsilon square = 0.27), and (9) Optimism to have an impact between students in study years 3 and 1 (H = 14.519, p = 0.037, relatively strong effect size epsilon square = 0.22) and between students in study years 2 and 1 (H = 22.569, p = 0.003, relatively strong effect size epsilon square = 0.34). Epsilon square effect size was calculated and interpreted as proposed by [71].
In the overall assessment of design thinking, third-year students performed significantly better than first-year students \((p < 0.05)\), while the differences between third- and second-year students were found to be non-significant \((p > 0.05)\).

4.2. SRSSDL Scores

The average total score obtained by the participants was 233.5 out of 300, with a standard deviation \(SD = 23.1\) and range of 183–283. This represents a high level of self-directed learning ability. Some 25\% of the sample obtained 218.2 points or less, while about 75\% of the participants obtained 249.8 points or less. Stratifying the scores as suggested by Williamson [65], no participant was placed at the lowest level (60–140), 35 (29.9\%) of the participants were placed at the intermediate level (141–220), while the majority (82, 70.1\%) were placed at the highest level. The internal consistency measured by Cronbach’s alpha coefficient was very high overall at 0.93. Figure 3 shows the students’ average scores on each subscale of SRSSDL across the study year.

The mean values of those who had answered the complete set of items \((n = 117)\) were contrasted. The differences observed between these items are significant, with \(p < 0.001\) (Friedman test: Chi-square value = 36.29; \(p = 0.000\); small effect size: Kendall’s \(W = 0.135\)). The differences between different constructs of SDL were calculated in order to find whether the constructs are evenly developed in students or some constructs are underdeveloped against others. The model of SDL is based on a dynamic conception of learning, whereby learners, independently and goal-oriented, disseminate their knowledge and skills in a particular field while at the same time improving their learning competencies by using appropriate cognitive, metacognitive, and motivational learning strategies [73]. Learning is thus not conceived as a sequence, but as a cyclic process that takes place continuously through several steps [61]. Thus, we found significant differences \((p < 0.05)\) using a Wilcoxon rank test between Awareness and subscales of Learning strategies, Learning activities, and Interpersonal skills. Moreover, a similar pattern was found between scales Evaluation and subscales of Learning strategies, Learning activities, and Interpersonal skills \((p < 0.01)\). In general, it seems that students’ awareness and ability for evaluation are more developed than their abilities for learning control and interpersonal skills.

Students’ average scores of the subscale items are shown in Table 2 and contrasted (using non-parametric tests) based on study year group as the differentiating factor. To find the differences between the groups of students regarding their ability for SDL across its subscales, a Kruskal-Wallis test was used with Dunn-Bonferroni post hoc tests. After Dunn-Bonferroni corrections we found significant differences at subscales of (1) Learning strategies between students in study years 3 and 1 \((H = 22.421, p = 0.000, relatively strong effect size epsilon square = 0.34)\), (2) Interpersonal skills between students in study years 3 and 1 \((H = 16.279, p = 0.016, relatively strong effect size epsilon square = 0.25)\), and
consequently in total score of SDL between students in study years 3 and 1 \((H = 16.036, \ p = 0.019, \) relatively strong effect size epsilon square = 0.24).

### Table 2. Students’ average scores on SDL across the study year and in total, and Cronbach’s α on SRSSDL questionnaire’s subscales.

| Subscale             | First-Year Students | Second-Year Students | Third-Year Students | Total     | Cronbach’s α |
|----------------------|---------------------|----------------------|---------------------|-----------|--------------|
|                      | M                   | SD                   | M                   | SD        |              |
| Awareness            | 47.02               | 4.54                 | 50.01               | 3.09      |              |
| Learning strategies  | 43.45               | 5.49                 | 47.40               | 2.98      |              |
| Learning activities  | 45.03               | 5.88                 | 48.20               | 2.52      |              |
| Evaluation           | 47.02               | 6.85                 | 49.8                | 3.65      |              |
| Interpersonal skills | 43.90               | 5.13                 | 45.02               | 5.77      |              |

Cronbach’s alpha coefficient values, based on the sample of this study, are shown in Table 2. The SRSSDL questionnaire in the present research proved to be moderate reliable, with Cronbach’s α values of the constructs between 0.71 to 0.83. Therefore, SRSSDL was found to be a reliable and valid instrument, and appropriate for use in higher educational settings [70].

### 4.3. SEM with the Bootstrapping Procedure

To test and evaluate multivariate causal relationships, an SEM was used. A common function of path analysis is mediation, which assumes that a variable can influence an outcome directly and indirectly through another variable. While we were conducting SEM five logical steps were utilised: model specification, identification, parameter estimation, model evaluation, and model modification [72,74]. It was hypothesised that students’ design thinking may affect their SDL of architectural subject matter. We also hypothesized that components of design thinking as exogenous variable effects would be significantly correlated with both positive and negative outcomes. Moreover, some possible correlations are expected between SDL variables, and these variables may also serve as a mediator for design thinking variables. As the path coefficients, standardised Beta \((β)\) weights were used, and they reflect strength and direction of change in predicting the dependent variable when the predictor changes. \(β\) weight ranges from +1—positively related to −1—negatively related [75] and may change from one sample to the next despite the context being the same. For the measure of model fit, an explained variance was used which shows very strong fit of the proposed model. The amount of variance in dependent variables that can be attributed to independent variables is considered as very strong, where \(R^2 > 0.26\) [70]. At model development, firstly we constructed the initial model using AMOS 24, which included nineteen constructs of design thinking as exogenous variables and five SDL subscales’ scores as endogenous variables. According to commonly used fit indices [76,77], we found a poor model fit. We observed a significant \(p\) value (0.013) in the Chi square test (17.74); the Chi square divided by its degrees of freedom was smaller than 5 (2.53). The goodness of fit index (GFI), comparative fit index (CFI), and Tucker-Lewis coefficient (TLI) values were not all greater than 0.95 (0.98, 0.99, and 0.61 respectively); the root mean square error of approximation (RMSEA) and root mean square residual (RMR) were greater than 0.05 (0.15 and 0.53, respectively). The GFI, CFI, TLI indexes are considered acceptable also at the > 0.90 level [78]. The probability level of the test of close fit (PCLOSE) was lower than 0.05 (0.03). These results indicated that the robust initial model did require improvement.

After the attenuation correction we developed a model, and according to commonly used fit indices, we found a good model fit. We observed a nonsignificant \(p\) value (0.57) in the Chi square test (58.57); the Chi square divided by its degrees of freedom was between values 1 and 5 (1.14) and met assessment guidelines by Hair et al. [79] for perfect fit. The GFI, CFI, and TLI values were all greater than 0.95 (0.96, 0.99, and 0.99, respectively); the RMSEA was smaller than 0.05 (0.003) while the RMR was greater than 0.05 (0.23). The RMR
is very sensitive on sample size and depends on the sizes of the variances and covariances of the observed variables [74,78]. The PCLOSE was greater than 0.05 (0.78). The probability level of the test of close fit was also higher than a proposed threshold level of 0.50 for a good model fit [77,79]. These results indicated that the path model did need special attention due to small sample size ($n = 117$). The basic method of model validation is to test a model by two or more random datasets from the same sample [80]. Therefore, the validation requires a large sample size or the bootstrapping procedure [80].

A path model of metacognitive design thinking factors with statistically significant ($p < 0.05$) standardized path coefficients is presented in Figure 4.

![Figure 4. Relationships between design thinking and SDL in metacognitive design thinking model.](image)

To empirically test the validity of this model due to the small sample size of 117 and no multivariate normality (critical ratio was of 3.157 > 1.96), the bootstrapping procedure was applied. The model to be tested was the same as the developed final model. The procedure obtained 5000 usable bootstrap samples which is sufficient for the bootstrapping procedure advised by [72,81–83]. Firstly, the adequacy of the entire hypothesized model, based on a transformation of the data so that the model fits the data exactly, was evaluated using the Bollen-Stine approach [77,84]. The distribution of the discrepancy function across the multiple bootstrap samples serves as an estimate of its distribution with the hypothesis that the model is correct [85]. A Bollen-Stine bootstrap $p$ value of <0.05 means that the hypothesized model should be rejected. In the present example, the $p$ value was 0.88, indicating that the model tested via the bootstrapping procedure was not significantly different than the hypothesized model.

Since the model was successfully validated via Bollen-Stine procedure, we applied bootstrapping procedure at 95% Bias-corrected confidence interval to prove that the bootstrap regression weight means based on the 5000 samples (unstandardized and standardized) for all of the paths/covariances/correlations in the model are unbiased. In the next
stage we compared the standard error (SE) of the mean bootstrap from all of the 5000 samples for each path/covariance/correlation with the SE-Bias between the original model and the bootstrap samples on each. The comparison continues until all possible ones in the model have been checked. In this study, all SE-biases from the bootstrap procedure were smaller than the SE’s from the mean bootstrap. Therefore, the bootstrap procedure indicated that all paths/covariances/correlations were verified as unbiased.

Descriptive analysis of the dependent variable of SDL revealed that students’ ability for SDL has been perceived as above the average, while the SEM analysis explains how predictor variables of design thinking can affect their metacognitive behaviour in learning. For the architecture students, an SDL performance as desired behaviour is well supported, since scaffold active learning framed with design thinking seems to be aligned well, with 13 out of 19 constructs of design thinking predicting SDL significantly ($p < 0.05$) in both directions, positive and negative.

The strongest positive predictor was found to be ability for teamwork ($\beta = 0.45$), which strongly predicts students’ interpersonal skills, followed by problem reframing which strongly predicts an ability for evaluation ($\beta = 0.43$) and awareness ($\beta = 0.35$), while learning orientation ($\beta = 0.29$) predicts an ability for evaluation of design work towards SDGs. Ability for abductive thinking was also found to be a strong predictor for students’ interpersonal skills ($\beta = 0.28$).

In addition, the ability to experiment or learn from mistakes strongly predicts students’ ability to engage in critical thinking and decision making necessary for successful evaluation of the design project and learning itself ($\beta = 0.30$), while students’ ability to design with users in mind strongly predicts the use of learning strategies when engaged in design activities ($\beta = 0.35$). The most negative predictor of SDL performance, ability for abductive thinking showed ($\beta = -0.50$), followed by ability for transdisciplinary collaboration at ($\beta = -0.29$). Ability for abductive thinking can be highlighted, since it has both negative and positive predicting values in SDL. Evaluation of learning outcomes of design education has two negative predictors and needs special treatment, since it is the basis for new self-assessment, which represents the first step in a new cycle of SDL, and some caution is needed, with clear definition and design of learning outcomes towards achievement of SDGs.

Interestingly, the metacognitive design thinking model revealed an interesting pathway, namely that students’ Creative confidence negatively predicted their ability to evaluate design projects and learn during design ($\beta = -0.23$). Indeed, we confirmed the findings of [62, 86] as they found that creativity is crucial to design thinking, where students are more likely to explore less tangible or subjective content and where transfer from this to tangible solutions is lacking, students may have difficulty monitoring their own learning. Creative confidence is more likely to be seen as valuing critical thinking as a basis for improving design learning [86].

5. Discussion

This section presents answers to the research questions, inferred from data collected using the two questionnaires. We close with a discussion on the implications of our findings and opportunities for further research.

5.1. Characteristics of Design Thinking in Undergraduate Architecture Students

Architecture students’ self-assessed design thinking ability can be estimated as above average. Students have evaluated themselves higher in ability for learning orientation as a key feature of design thinkers. It seems that the main source of learning sustainable design could be learning through observation, rapid prototyping, and problem definition and hypothesis formulation, as also argued by [7, 22, 66]. An ability for problem reframing can also be crucial for countering new problems towards achieving SDGs [4, 23], and inventive thinking which also includes adaptability, managing complexity, and self-direction [10], while an ability for empathy could be useful at design of user experience, needed for
sustainable architecture [21,24,56]. An ability for experimentation or learning from mistakes or from failure, transdisciplinary collaboration and desire to make a difference can be useful for evaluation of performance in response to social, economic, and natural environments, for assessment of users and viability of designs [15,87], enabling breakthrough insights and solutions from diversity [62], and for developing the skills, structures, and processes to generate value from valuable insights [86].

Figure 2 also reveals that students have marked shortcomings. Ability for risk taking is not yet well developed, which points to a lack of design subject matter knowledge, pedagogical content knowledge and technological pedagogical content knowledge, as also argued by [14,62]. Moreover, it is very necessary for innovation learning, and it might be that translation of cognitive and affective empathy at design thinking into conative (inclination for action) had not been realised yet [56]. The second design thinking shortcoming is in ability for ambiguity and uncertainty tolerance. These students are more likely to avoid tasks where the outcome, time needed and a path to the outcome are rather unclear, and thus we support the findings of [7,13,20,54,62]. It seems that a too generalised view and articulation of design thinking were used during design, which led to passive or surface learning. Thus, a shift to situated, more embodied material practices is needed, as also proposed by Kimbel [30].

It was also found that design thinking in architecture students is not evenly developed across the subscales of design thinking to the level where students are fully aware of the design process, as defined by Stanford University [12] and articulated by Dym et al. [22] in general engineering education, and Dorst [51], Martins et al. [7] for architecture education. In particular, three problematic subscale performances were found, namely Ambiguity and uncertainty tolerance, Embracing risk, and Mindfulness and awareness of process. In addition, it may be that some subscales are also at risk, namely Abductive thinking, Creative confidence, Human centeredness, Team working, Experimentation, or learn from mistake or from failure. It could be that students with less pronounced design thinking in the aforementioned subscales have difficulties in problem definition, user experience design, creative ideation, and prototyping as argued by [24,54,56,88]. Therefore, students might have difficulties in achieving the SDGs [9], especially in design for partnership, design for resilient communities, and design for rethinking resources, where a need for transdisciplinary learning and systems thinking is desired [51,89].

5.2. Characteristics of SDL in Undergraduate Architecture Students

Students’ SDL was assessed against five subscales. A large majority were placed in the highest level of SDL (221–300 points) defined by Williamson [69]. We can argue that architecture students engaged in this study have an above average level of (1) reflective process control (control of situational actions, control of environment and control of personal feelings), (2) reflective process knowledge (task awareness, cognitive strategies knowledge, self-awareness), and (3) reflective process monitoring (personal feelings monitoring, situational actions monitoring, idea generation, and development monitoring). SDL was found to be a key player in sustainable architecture design, as also argued by [5].

Students show high awareness of the learning process, they can identify their own learning needs and are responsible for own learning. Interestingly, no differences were found across the study years of students.

A similar situation was detected at the scale of Learning activities and Evaluation, where students at all grades are able to identify the important points when learning, using concept mapping and ICT effectively, are able to relate knowledge with practice, able to monitor and control learning progress, identify areas of strength and weakness, and to assess to what extent the learning goal they have set has been achieved through a chosen learning strategy; these abilities are developed evenly across the study years.

Students differ significantly ($p < 0.05$) on the subscales of Learning strategy and Interpersonal skills; third-year students have evaluated themselves significantly higher (49.67) on the Learning strategy scale than first-year students (43.45) with a strong effect size of
0.34 and on the *Interpersonal skills* subscale (48.86, 43.90) with a relatively strong effect size 0.25. The third-year architecture students’ sample performs significantly better on feedback seeking, experimentalism, interactions, diversity of contents, use of ICT, decision-making items, as a part of the *Learning strategy* subscale, and also significantly better on integrative thinking, collaboration, communication, emotional intelligence, negotiation, persuasion and influencing, social awareness, conflict resolution, and mediation items as a part of the *Interpersonal skills* subscale. These results are well aligned with some findings of [7,10,14,54].

It seems that activities conducted in the architecture study from first year to third year utilised design thinking as well as a student-centred method based on constructivism and social-cognitive theory, and students showed significant progress on the aforementioned two subscales of SDL. The use of meta-cognitive design thinking as an innovative approach to teaching and learning can be seen as a means of improving the quality of education towards sustainability, as also argued by [10,48].

As the present research was not a longitudinal study, the results should be treated with caution and larger studies need to be conducted to confirm these findings and provide further insights for effectively integrating the SDGs into the current curriculum.

### 5.3. Relation between Architecture Students’ Design Thinking and Their Self-Directed Behaviour

Student awareness of learning is well explained by design thinking ability for re-definition or problem reframing and through ability for multitasking and an ability for prediction, which is consistent with the findings of [10,62]. Reflective process knowledge affects both students’ task- and self-awareness and learning strategies knowledge, which is also affected by the ability for inclusion of user experiences in the design process. Moreover, this may show the way to solving complex and strategic problems, where customer co-creation should be a key requirement, as also argued by [62], and for problem reframing in a self-directed way, as stated by [48]. Design thinking may be the right way to integrate SDGs into the architecture curriculum, since as an educational approach is able to solve some of the most complex, open-ended, and ill-defined problems in the real world, as suggested by [16], and on a scale of dimensions proposed by [9].

Students’ ability to master learning activities is very connected with design thinking through application of planned learning pathway to the final design outcome, exploiting user experiences which define the direction of the design solution [5,51,56,62,90]. Students’ learning orientation focuses on what they learned through observation, experiences and feedback from the learning environment, peers, teachers—to see a problem as an opportunity to learn—and in that regard, they will effectively master the subject matter using different strategies, methods, educational technology, and by exploiting self-efficacy and through critical thinking in design activities. These support the findings of several authors well, including [13–15,54]. Reflective process control is focused on control of situational actions, control of environment, and control of personal feelings [5].

Moreover, students’ ability to control and monitor their own learning is largely linked to empathy with users’ needs and desires, user experience design, reframing of problems, and orientation towards mastery learning through learning by doing using ICT, also argued by [90]. This indicates an extensive use of technological pedagogical content knowledge among students for effective learning by design, and as it seems, these students have developed an ability to substitute, augment, modify, and redefine the learning process itself presented according to the SAMR model [91]. Thus, we confirm the findings of [91–93] that a comprehensive use of technological pedagogical content knowledge in design, together with the SAMR model, helps to select and evaluate the level, type, and extent of ICT use in learning and to support a transformation of learning. Students’ evaluation process is strongly explained by independent variables in both directions, positive and negative. Students engaging with learning, tasks, and assignments are more likely to get feedback from instructors and peers, where both success and failure inspire the students for further learning. Using different mechanisms and tools, e.g., checklist, portfolio, quizzes, and SWOT analysis for self-assessment and self-orientation can enhance further learning, which
is consistent with [5,7,48,54]. Evaluation ability is strongly supported by students’ learning orientation, an ability for problem reframing and using user experiences in the design process and evaluation. As self-directed learners, students have a desire to learn, including learning about others, challenging existing frameworks, and seeking new contexts in which to learn something [5,48]. Moreover, introducing ICT in design through the SAMR model [91] and the Pedagogy Wheel [93] could improve students’ ability to assess and positively direct their creative confidence towards assessment.

Moreover, three negative predictors of monitoring individual learning were found, namely the ability for abductive thinking, collaboration over subject matter disciplines and creative confidence. Students who are able to invent alternatives, new conditions for future work and learning, and draw conclusions from incomplete information will have fewer difficulties for self-assessment or in evaluating their own work. It seems that these students can see final outcomes or project as not the ultimate or ideal one, but they always see opportunities to improve or upgrade it, as also argued by [18,26,51]. The students probably still do not see the big picture of design science and are not familiar yet with the competencies brought from other disciplines to be employed in the design tasks. Special attention should be paid to the design of tasks and activities, because students with greater creative self-confidence need more tangible sources and learning outcomes. They need more experimental work and more feedback, especially from peers, the content should be more challenging for these students, and they need to feel a sense of achievement, especially when inspired by the work of others. Design thinking should allow for multiple concept or context maps and a portfolio so that students can more easily track and monitor their own learning and designing, which is also suggested by [23,30,54]. As design thinking includes a phase of prototyping, this can be considered as an optimal solution to improve creative confidence in order to improve SDL, as also argued by [13,15]. Nowadays, the use of various 3D digital technologies, e.g., computer-aided design and modelling, 3D scanners, 3D printers and computer numerical control machines for prototyping can improve the overall design, critical, and creative thinking towards the SDGs defined for architectural education, also argued by [9,10,13,15]. When the use of ICT is purposeful and didactic, for example, using the SAMR model [91] and education wheel [93], which guides us to think about teaching in the digital age, linking considerations of the functions offered by ICT with changing learning methods, increasing motivation in students, improving cognitive development and long-term goals of learning and education [92,93].

Students’ interpersonal skills are well explained by design thinking constructs. Moreover, it seems that design thinking and designs can develop the students’ empathy, cooperation, negotiation, leadership, and social awareness as personalised and self-paced learning, from process-based to project and problem-based content delivery, using integrative and critical thinking and creativity. Thus, we support the findings of [5,7,48,54].

5.4. Guidelines for Using a Path Model towards Sustainability

Based on the results of the study, available literature in cognitive science, and an ICT use in education, guidelines can be suggested to ensure a sustainable design. (1) Use a framework within design panels for developing and achieving the SDGs defined by [9]. (2) Follow the systematic approach provided by the design thinking model. (3) Use a SAMR model within technological pedagogical content knowledge to effectively incorporate ICT into design activities, and also to assess progress and success in design learning. (4) Use of user experience design within design thinking to enable interaction design involving multiple stakeholders in natural, economic, and social environments. (5) Use a pedagogy wheel developed by [93] with a variety of technology-based ideation techniques to build students’ creative confidence and design learning outcomes. (6) Pay special attention to the prototyping phase, especially when digital technology is used in design. Provide transfer from virtual models to physical models on a large scale to build students’ creative confidence and critical thinking. (7) Design thinking processes should
incorporate rationality and constraints as an important aspect with regard to the SDGs. Rationality should be included especially in the problem definition and prototyping phase.

5.5. Limitations of the Study and Future Work

The limitations of this study are as follows: (1) Sample size: a much larger sample would have contributed to the generalizability of the results; Diversity: the sample of the study was limited to one university and a large majority of the sample represents female students; consequently, the results may not reveal the performance of different universities (public and private) and design studios. (2) Methodology: only questionnaires are used in this study. There was no qualitative data in the study; therefore, the study was made from students’ perceptions while educators’ perceptions are absent. In addition, conducting experimental research with different groups of students provides deeper insights, especially when experimentation and other “hands-on” skills can be measured. (3) Measuring students’ academic, social, and cognitive outcomes would have expanded the explanatory power of the model. (4) Self-assessment of design thinking relies on only one instrument and may be biased. (5) An assessment of the different technology uses and experiences within the design process is missing.

Future work of this study should include larger sample sizes from different universities in the field. In addition, to further support this, a larger experiment should be designed where design thinking is implemented in technology-enhanced learning environment with a specific SDGs taxonomy that aims to promote learning and acquisition of higher order thinking skills. Based on the results of the study, the most appropriate design thinking implementation for future study can be seen in the design for rethinking resources, such as materials we use, methods we apply, and life cycles of products or processes, as one of the ways of SDGs integration in curriculum suggested by [9].

6. Conclusions

In this study, researchers explored interactions between design thinking and self-directed learning in architecture students. The results indicate a strong possibility of using a design thinking method to develop self-directed learners. The path model developed in this study provides directions and strength to these directions as to how design thinking predicts students’ self-directed learning, as it is perceived by students. This can provide insights for educators seeking to enhance the design process and its outcomes for learners. In this regard, several subscales of design thinking were revealed which affect self-directed learning on reflective process knowledge, control, and monitoring. Moreover, when applying social cognitive theory in the development of self-directed competencies in undergraduates, a triadic model foresees reciprocity of actions, which means when we develop self-directed learning in students, their actions can shape the learning environment as well as personal factors such as cognition, affective states, and self-efficacy.

This study revealed opportunities for using design thinking to develop self-directed learning for sustainable development goals’ achievement, where metacognitive thinking may play an essential role in design idea generation and development, prototyping, testing, and evaluation, and that it is an important part of the creative process in sustainable architecture design.

Students’ interpersonal skills can be developed through teamwork, with problem-based tasks, thinking outside existing frameworks despite the fact that this can lead to failure or mistakes while learning or doing. This connection points to transfer of team knowledge or learning. Feedback seeking, experimentalism, openness to diversity, embracing risk and mindfulness, and awareness of process are traits that architecture educators should develop in their students to improve perceived design thinking ability. Incorporation of user-centred design, and divergent, convergent, and abductive thinking, teamwork with transdisciplinary content and processes in the architecture classroom are recommended as ways to foster self-directed learning for sustainable development goal achievement.
Self-directed learning is strongly predicted by the selected design thinking factors, especially by the ability to exploit user experiences in design, problem reframing, teamwork, mastery goal orientation, and abductive thinking. In turn, self-directed learning developed in that way can enhance a shift in learning content and experiences for developing interpersonal skills, digital skills, innovation and creativity skills, and global citizen skills needed for Society 5.0.

Future research work is oriented toward determination of a skills transfer model on how the aforementioned skills can be developed and nurtured in undergraduate students and afterward transferred by adapting a model where individuals with developed Society 5.0 skills create, adapt, and transfer their own model downstream to the high school level for use.

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