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Developing a Framework to Predict Factors Significant for Creative Architectural Design Performance of Freshmen and Senior Architecture Students, by Adopting and Validating the CEDA*

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This study aims to provide a framework to predict factors significant for creative engineering design performance of freshmen and senior architecture students. Since different environments demand utilisation of a rather interdisciplinary approach of design-cognition types of teaching and learning, an advanced model of creative engineering design process has been proposed to measure multifaceted effects of the architecture study programme. For the study, 108 freshmen and 98 senior architecture students were surveyed for attitudes towards engineering, proactivity, situational interest, perception of learning, and satisfaction with design work environment and tested for creative engineering design on fluency, flexibility, originality and usefulness of designs or solutions generated. Two models were developed based on social cognition supported by self-determination theory using predictive modelling. Results demonstrate that for freshmen creative design work is not well explained by the social-cognitive theory model, while for their senior counterparts the same is strongly explained. Student proactivity was a crucial predictor in perception of control over learning solution-based creative design work, especially in senior students. As the strongest negative predictor, tediousness toward engineering was identified in social-cognitive learning, pointing to the importance of engineering knowledge, beliefs, opinions, emotions, and responses towards wider definition of technology and engineering. Such students more likely do not utilise potential of technology and engineering to work on problem- and solution-driven design tasks to develop creativity. The findings are of particular interest for architecture education curriculum designers, design course conductors and different organisations to provide sustainable, creative and market-competitive design solutions.

Keywords: design process; architectural education; engineering creativity; social-cognitive framework; predictive modelling

1. Introduction

The importance of the quality of the education system, as one of the key factors for competitiveness in the innovation-driven economy, is recognised worldwide, as stated by [1]. There is also a growing awareness that innovative learning is a key element of any competitive education to develop the most valuable skills needed on the labour market for the 21st century [1].

The key challenge of the education system is to deal with global mega-trends, e.g., globalisation, demographic changes, digitalisation, intensive technological development and climate changes, and health care without further widening social and economic disparities, as well as to the detriment of the environment [2]. Possible solutions have been ascertained in higher order thinking of educational goals and mastery of student-centred goal orientation in a real environment where they cope with life challenges using design, design thinking and systems thinking [3]. Nevertheless, the acquisition of competencies and skills such as collaboration, perseverance, communication, critical thinking, authentic problem solving, teamwork, creativity and innovation depends mainly on the modelling of teaching and learning itself. The systematic development of these new approaches and methods entails targeted contextual and conceptual learning contents that enable the development of broader interdisciplinary learning outcomes and innovative learning [3, 4].

Architecture education nowadays is not an exception where a need for change is felt. Together with engineering, it seems to be affected a lot and their concerted action is needed. More than ever, a professional rethink is needed about how architects and engineers cooperate to cope with 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 [5]. Moreover, interdisciplinary work of architects and engineers demands considerable skills, commitment and creativity to optimise their creative design process [5, 6]. Design-based

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learning might appear as regenerative learning, especially for senior students, as newly promoted design education, with the following phases: sensing, engaging (authentic involvement), learning by doing and working with feedback and feed forward [7] and applying a social-cognitive framework as a reciprocal relationship between a person, his/her environment and his/her behaviour [8, 9].

Since designing 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 are different [10]. It 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. By understanding this way, we can shape the way architecture students practice creative design since there is a growing interest in many educational organisations to educate and nurture competent students who will acquire labour market competitive skills and competencies [10].

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 [11]. For institutions to meet these standards, they must understand design and the manner in which students learn design. Because of significant importance and necessity of design, a new curriculum for architecture also involves the concept of design in the first Bologna cycle [11], while the previous curriculum had the majority of the design 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, and 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 [11].

An increased interest in using design and design thinking as an educational approach to foster creativity and innovation in higher education has raised several questions. It is particularly interesting as to how to optimise creative engineering design process as an approach to innovative behaviour and in particular how to identify and evaluate the influencers on its implementation in higher architectural education.

2. Literature Review

Design thinking appears as a cognitive process where individuals in the design process combine empathy, creativity and rationality to analyse and adapt solutions to specific contexts [6, 12]. More than before, the design process contextualised in higher education requires a metacognitive approach to developing creative processes that can be made tangible for the designers, reflecting previous experience and knowledge, and thus imparting the designer with the ability to solve a particular design challenge where user experiences are involved [7, 12, 13]. Several authors have studied design creativity from a standpoint of idea generation and exploration [14–16], creative and collaborative stimulation [17, 18]; some of them expanded general design to engineering design [5, 19] and introduced the usefulness of product or solutions as a part of the creative engineering design performance. It seems that design is rather utilised as an activity-based approach where students' priorities are reflected in user research, idea generation, and user testing, while developing concepts and planning and finalizing design projects seem to be more difficult for them as argued by Tate [20].

Very recent researchers point out the social-cognitive learning of design [9, 21] using different methods (experiential learning, project-based learning, problem-based learning, blended learning and design thinking), while some highlighted the role of self-efficacy at engineering design [22, 23] while motivational beliefs can be decisive especially in freshmen to pursue engineering design activities [22, 24]. Moreover, design specific learning outcomes across different higher education majors and typical learning outcomes for art and architecture education were detected as context, communication, and creativity followed by collaboration, critical thinking and technical skills (strategic handling and management skills and craftsmanship) [25]. It seems that the so-defined learning outcomes can be achieved using solution-based design of abductive reasoning [26]; thus, social-cognitive framework can be fitted well to design [9].

The reproductive way is a traditional design process, on which designers and engineers do (create) a design that operates with a known working principle, and within a set scenario of value creation [25], while the biggest challenge nowadays is abductive thinking which leads to aspired value [26]. It is much expected that freshmen are more likely to use information-driven design cognition type or knowledge-driven reproductive way of design [15]. Senior students as experienced designers are more likely to use strategic approach to tackle creative challenge and derive both a thing and its working principle in the framework as the general implication, and it is in direct connection with a specific value set by user analysis [25]. It might be that solution-driven design cognition type significantly predicts creativity outcomes as argued by Lu [15]. Students practising problem-driven design appear as universal for both, freshmen or seniors, but deductive and inductive reasoning at problem solving might not predict creative design achievements as argued by Lu [15]. Moreover, van Dinther et al. [27] argued that reproductive way of learning process and imposing of a trial-error approach might decrease students' self-efficacy and consequently their creative performance, interest in the subject, motivation, satisfaction of basic psychological needs, and proactive behaviour as a proximal variable [28] what can be expected especially at freshman students.

Proactive behaviour can be seen as an active and self-initiated human response to changes and challenges in the social, economic and natural environment and is closely linked to the development of new technologies, products or process [28, 29]. Proactive people initiate changes, take action, and persevere until meaningful change ensues in the achievement of their goals in contrast to passive people who just adapt to their undesirable circumstances [12, 30]. Thus, a proactive architecture student will do extensive monitoring in different environments, to research users, identify new opportunities, perform situation analysis through situation detection, exploit historical data, integrate historical data with current state and make prediction or several models, which are useful for decision making followed by action-based new, original, useful and advanced abduction-based design. A proactive architecture student will design systems thinking, master goal orientation, and collaborate in different networks, both physical and virtual [29].

Hero et al. [1] and Klaeijsen et al. [28] have systematically reviewed studies exploring creative behaviour for innovation learning. Several factors influencing behaviour were revealed, for example, tasks with different cognitive demands, self-efficacy, creativity, engagement in work or learning, motivation, and satisfaction with learning or work [28], while Hero et al. [1] identified flexibility and stability in relation to learning activities, achievement orientation, social skills, self-regulation, critical and creative thinking, and content knowledge, together with the ability to create or make. Several authors argued that students' attitudes towards technology and engineering can be used to predict their perceived level of control over learning and creative performance [5, 6, 19, 31]. In addition, attitudes can moderate engineering thinking and proactive behaviour, especially when tasks involve higher-level cognitive demands [10, 12, 19, 32].

Different cognitive demands trigger different levels of situational interest in learning [32, 33] as an affective response to the assigned task. Situational interest (triggered and maintained), together with perceived learning value and satisfaction with the course design, can influence creative design performance, especially in terms of the level of fluency, flexibility, originality and usefulness of designs or products in relation to learning and working in studios, seminars, lectures, and workshops [32]. Moreover, both intrinsic motivation and autonomous types of extrinsic motivation are conducive to engagement and optimal learning in educational contexts [33]. Niemec and Ryan [33] argued that perceived learning value should be enhanced using effectance-relevant and optimally challenging design tasks, with several types of feedback, while relatedness should be based on strategies which include conveying warmth, care, and respect to students. Students autonomy in the design process should be enhanced through real-life meaningful learning contexts involving students' feelings about learning topics as much as possible [33], and they will integrate regulation and internalise learning value [34]. Some limitations in the students' attitudes towards design process were discovered such as the limited use of digital tools and technology for problem solving, a lack of project management, lack of explicit concept selection, a focus on a single concept and an appreciation for several iterations in design process [20], which might decrease their design self-efficacy [8, 27].

A creative person is able to produce a wide range of ideas, processes or products that are novel, original, unexpected, imaginative and useful, as well as be appropriate or adaptive regarding task limitations and constraints [35]. Creativity plays a significant role in design problem-solving activities where students can master their experiences and therefore inspire a strong sense of efficacy [27]. In contrast, those who demand more information or want to acquire more skills and knowledge from their creative work or learning feel less useful and less creative if the learning environment and tasks are not well designed [35, 36].

A creative design process should take into account that the design problem is always subject to conditions which serve as benchmarks for judging the solution and, more likely, is a real-life decision-making problem where physical solution optimisation and selection of solutions is needed due to high level of abstraction in design process using advanced design theories. Thus, in design work, both convergent and divergent thinking are utilised, together with critical thinking as they present key indicators of product quality and capability in the sense of usefulness and functionality [15]. The design process may vary based on the year of study, since senior students might have higher quality solutions, spent more time solving the problem, considered more alternative solutions, and made more transitions between design steps than the freshmen did [10].

A complex view on design was presented by Dorst [26], where abduction leads to most creative and innovative designs. 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 [26]. Designers cope with the probability of solution or design realisation when the rule is set, while result and example are very often subjected to trade off in an extensive decision-making process. It points to the higher level of students' motivation, productivity and engagement if they want to proceed complex design task and to shape innovative behaviour. An affective commitment and intrinsic motivation can be a key to success in 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, argued by Ryan and Deci [34].

Numerous studies show that design and design thinking have gained in popularity and importance in the context of higher education over the last decade [3, 37–41, but these studies rarely address the predictive effects on creative engineering design implemented in architecture education and framed in social-cognitive theory of learning where motivational beliefs determined by self-determination theory might be decisive.

Despite the large number of models, several common drawbacks have been identified, such as a lack of deep understanding of cognitive aspects and motivational factors [15, 28], the effects of various uncertainties and individual differences on creative behaviour, the inclusion of attitudes towards engineering, and the impact of proactive personality on creative design performance [31]. However, the impact of the architecture curriculum on the creative engineering design performance of architecture students is not well understood.

Against this background, the following research questions (RQs) guided the study:

- RQ1: What is the relationship between architecture students' proactive personality and attitudes towards engineering and their perception of the learning of the architecture subject matter for freshmen and senior students in the framework of social-cognitive theory?
- RQ2: What is the relationship between architecture students' perceived control over the learning of the architecture subject matter and their behaviour in terms of creative design performance for freshmen and senior students in the framework of social-cognitive theory?
- RQ3: Do architecture students' proactive personality and attitudes towards engineering directly predict creative design performance for freshmen and senior students in the framework of social-cognitive theory?

3. Methodology

In this research, an empirical study is designed and conducted to evaluate the creative design abilities of both freshmen and senior-level undergraduate architecture students. A conceptual framework that considers factors significant for creative engineering design was built on Bandura's social-cognitive theory [8] together with application of self-determination theory to the educational practise [34], as shown in Fig. 1.

Social-cognitive design perspective is based on reciprocal causation of personal factors, environmental influencers and behaviour patterns [8]. For the purpose of this study, we examined architecture students' attitudes towards engineering as cognitive (beliefs and opinions held), affective (interests, emotions and feelings), conative (inclination for action), and evaluative in the form of positive or negative response to stimuli in the context of engineering subject matter and activities. To cope with the current changes in the social, economic and natural environments, a proactive personality of students might enhance their design activities in the social-cognitive learning framework [9].

When designing, students with higher level of proactivity feel confident of what they are doing, are more mastery performance oriented, and feel a sense of volition when understanding the value of activity [34]. It seems that students as individuals with higher creative design ability tend to regulate their design behaviour as a function of personal interest and values, based on autonomous motivation [9, 42].

To investigate role of influencers in a creative design performance (dependent variable), different class ranks of students were used as independent variable. Freshmen were classified as those enrolled in first-year architecture courses, while seniors were defined as those in final-year courses. To measure the creative design performance, all students were subjected to identical tasks. Noise factors, which

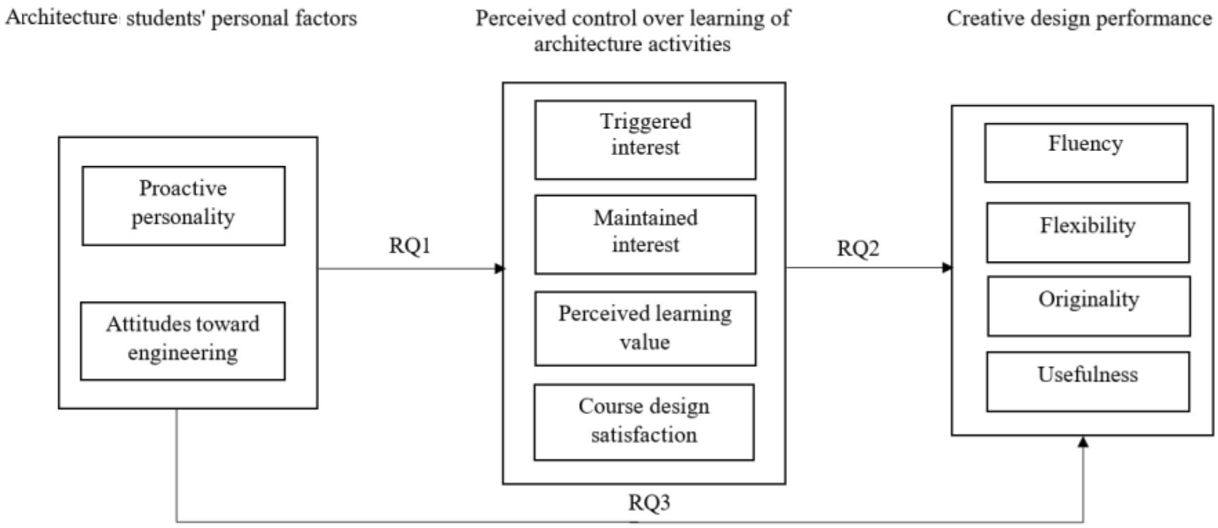

Fig. 1. Social-cognitive theoretical framework of personal factors, environmental influencers and creative design performance supported with a self-determination theory also showing the relationships among the research questions RQ1–RQ3.

were not controlled in this study, include student demographics, e.g., grade point average, gender, social-economic status... and prior experience levels, e.g., internships, special skills and competencies acquired in out-of-study program activities.

3.1 Sample

The research sample consisted of 108 freshmen (85 females, 23 males) and 98 seniors (54 females, 44 males) from the Cracow University of Technology, Poland, during two consecutive academic years from 2017 to 2019. The sample included significantly more females (n = 139, 67.5%) than males (n = 67, 32.5%). The average freshmen age was 19.3 and the average senior age was 23.5 years. The students were informed of the purpose of the study. No reward was provided for participation, and they were free to withdraw from the study at any stage. Studies with freshmen were conducted in the first semester of each academic year, while their seniors were surveyed in the second semester, close to the end of their study.

3.2 Instruments

Perceived control over learning of architectural activities and level of proactive personality were assessed using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) using a questionnaire called *Action and me.* The questionnaire consisted of five constructs: (1) proactive behaviour (five items), (2) triggered interest (four items), (3) maintained interest (five items), (4) perceived learning value (four items), and (5) satisfaction with course design (seven items). The questionnaire was based on the Avsec and Sajdera [31] questionnaire for assessing the level of engagement in technical and engineering activities.

Attitudes towards engineering were assessed using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) using a questionnaire titled *Engineering and me, which* included six sub-scales as constructs: (1) engineering career aspirations (four items), (2) interest in engineering (six items), (3) tediousness towards engineering (four items), (4) suitability of engineering for both genders (three items), (5) consequences of engineering (four items), and (6) difficulty of engineering (four items). The 25-item questionnaire was based on [43] a questionnaire for measuring attitudes towards technology with a focus on engineering activities.

To assess creativity specific to engineering design, a test of Creative Engineering Design Assessment (CEDA) [19] was used on the following dimensions:

- *Fluenc*y (number, total designs, problems solved, descriptions, materials, existing and potential users, and alternative uses or functionalities).
- *Flexibility* (types or classifications, categories or varieties in total designs, problems solved, descriptions, materials, existing and potential users, and alternative uses or functionalities).
- *Originalit*y – for each design/solution an assessment scale from 0-dull to 10-genius was used.
- *Usefulnes*s – a scale from 0-not useful to 4-indenspesible was used to assess practicality of design solutions based on reliability, number of purposes, and applicability as at present or new uses in the future. Usefulness may distinguish from general creative ability and represent sustainability of products/designs typical for engineering [19].

3.3 Procedure and Data Analysis

The study was conducted in a real-life classroom in the authors' presence. Each student was requested to complete two questionnaires and a CEDA test using the paper and pencil method, beginning with *Engineering and me*, followed by *Action and me*, and the CEDA test.

Data analysis was performed using SPSS v.25 to obtain the freshmen and senior students' average scores of the dependent variables. Cronbach's alpha coefficient was used to assess questionnaires' and test's reliability. Multiple regression analyses were performed to investigate whether predictor variables significantly predicted architecture students' creative design performance in both freshmen and senior students. Both models were juxtaposed and analysed against the social-cognitive framework supported by self-determination theory.

Table 1. Reliability of instrument sub-scales

Instrument	**Cronbach α**
***Engineering and me* questionnaire**	
Engineering career aspirations	0.95
Interest in engineering	0.82
Tediousness towards engineering	0.81
Suitability of engineering for both genders	0.90
Consequences of technology and engineering	0.81
Difficulty of engineering	0.84
***Action and me* questionnaire**	
Proactive behaviour	0.86
Triggered interest	0.87
Maintained interest	0.94
Perceived learning value	0.90
Satisfaction with course design	0.91
CEDA test	
Fluency	0.92
Flexibility	0.90
Originality	0.91
Usefulness	0.89

4. Results

The chosen instruments were assessed for evidence of reliability in terms of the criteria used in social science research [44]. Table 1 shows the reliability of the instrument sub-scales based on Cronbach's α. All the instruments used in the present study proved to be moderately to highly reliable, with Cronbach's α >0.80 [44].

4.1 Descriptive Statistics

Before testing the hypothesised relationships, a descriptive analysis was performed. Student's' average scores on their personal factors are depicted in Fig. 2. In general, architecture students reported above average proactivity and attitudes towards engineering, also considering scales of *Tediousness towards engineering* and *Suitability of engineering for both genders* which were reversed. Only perception of engineering difficulty seems to be neutral; it means not too difficult or not too easy for study.

Levene's test revealed no statistical significance at the 0.05 level for all personal factors on both mean- and median-based calculations. A MANOVA was conducted using the students' personal factors to determine whether their self-reported average ratings were affected by the year of the study. Statistically significant differences ($p < 0.05$) were observed in relation to proactivity ($F = 12.938$, $p = 0.000$, partial $\eta^2 = 0.061$), engineering career aspirations ($F = 3.986$, $p = 0.049$, partial $\eta^2 = 0.019$) tediousness towards engineering ($F = 5.630$,

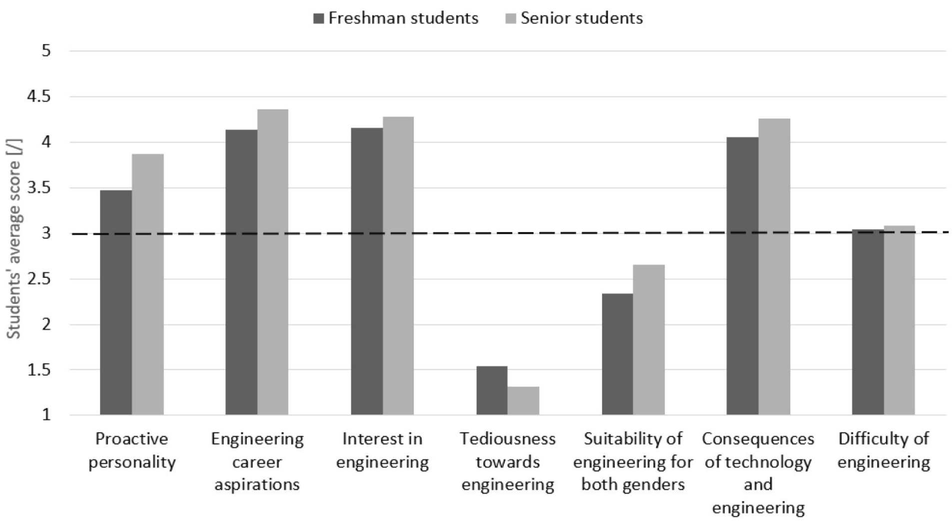

Fig. 2. Freshmen and senior students' proactive personality and their attitudes towards engineering with a mid-point 3 (dashed line).

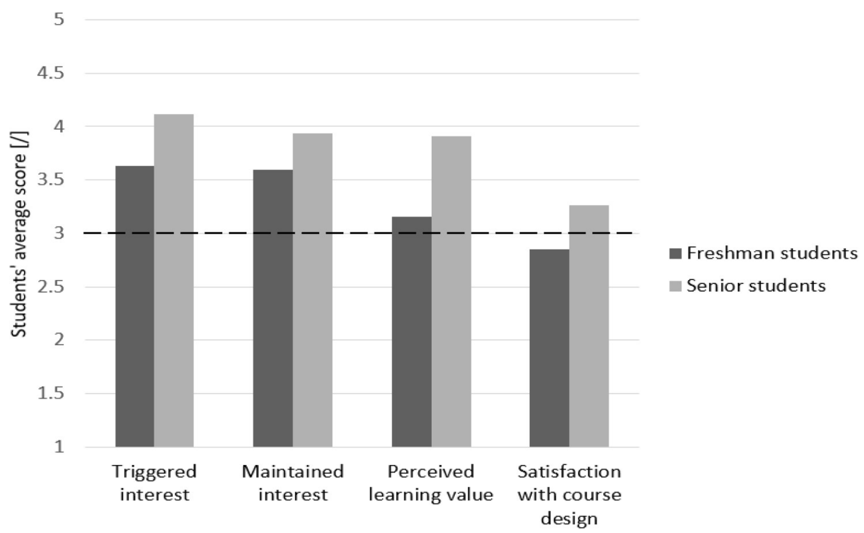

Fig. 3. Freshmen and senior students' perceived control over learning of architectural activities with a mid-point 3 (dashed line).

p = 0.019, partial η^2 = 0.027), suitability of engineering for both genders (F = 4.091, p = 0.044, partial η^2 = 0.020), and consequences of engineering (F = 5.961, p = 0.015, partial η^2 = 0.028). Effect size of partial η^2 is estimated as small to medium [45].

Freshmen and senior architecture students' engagement in architecture activities may be reflected in different ways as depicted in Fig. 3.

Students' perceived control over learning is of significant importance especially when social-cognitive theory is applied to design learning [27]. Senior students' perceived control over learning of design activities is above average while freshmen reported lower ratings, especially at satisfaction with the course design, which was expected, because they were surveyed in the first semester of the study where in a vast number of cases a traditional approach to teaching is utilised and a general subject matter is taught to them in order to elicit their previous knowledge and balance the range of skills with which they are enrolled in the study programme.

Levene's test for equality of variances showed no statistical significance at the 0.05 level for all personal factors using both mean- and median-based calculations. A MANOVA was conducted using the students' factors of perceived control over learning to determine whether their self-reported average ratings were affected by the year of the study. Statistically significant differences (p<0.05) were found in relation to all factors, namely in triggered interest (F = 16.274, p = 0.000, partial η^2 = 0.074), maintained interest (F = 5.897, p = 0.016, partial η^2 = 0.028), perceived learning value (F = 29.488, p = 0.000, partial η^2 = 0.13), and in satisfaction with course design (F = 7.442, p = 0.007, partial η^2 = 0.035). Effect size of partial η^2 is estimated as small to medium whereas in perceived learning value can be high [45].

At creative engineering design assessment, freshmen had a mean, M = 76.12 with standard deviation SD = 23.59, while their senior counterparts scored higher with M = 107.53 and SD = 23.98. Their creative design performance ranged from 6 to 131 points from a maximum possible score of 284. Senior architecture students demonstrated higher design ability and outperformed their freshmen counterparts in total score and in all dimensions of CEDA as shown in Fig. 4.

The level of creative engineering design performance of architecture students is very comparable with the level of other engineering students (chemical, electrical, mechanical and computer engineering) what we have measured in our previous research [46]. The CEDA developed by [19] has identified specific skills necessary for successful engineering design across engineering disciplines and architecture, and these skills including 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 [47].

To compare between-subject effects, we ran Levene's test for equality of variance across the year of study. The test confirmed that the study sample did not violate the assumption that the sample is normally distributed in total score and across the dimensions of CEDA (p > 0.05). MANOVA tests of between-subject effects revealed significant differences (p < 0.001) with strong effects for architecture education for total score (η^2 = 0.305) and on subscale of fluency (η^2 = 0.349),

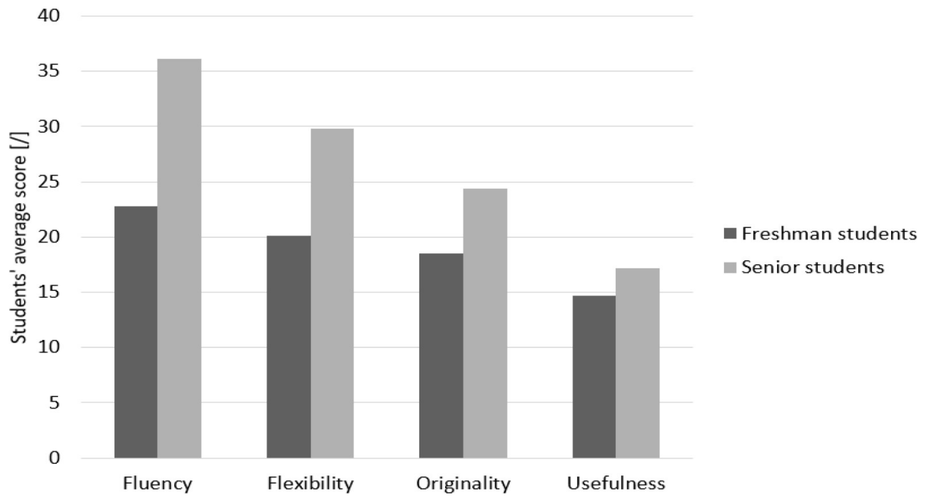

Fig. 4. Freshmen and senior students' creative engineering design performance across dimensions of CEDA.

flexibility ($\eta^2 = 0.318$), and originality ($\eta^2 = 0.146$), while on subscale of usefulness, a medium effect size was estimated ($\eta^2 = 0.087$) [45].

4.2 Predictive Modelling

In order to compare creative design process in freshmen and senior students through the lens of social-cognitive theory supported by the self-determination concept, a predictive modelling was done using regression analysis. A linear regression analysis was used, where beta (β) weight reflects strength and direction of change in predicting dependent variable when predictor changes. β weight ranges from +1– positively related to –1– negatively related [48] and may change from one sample to the next despite the same context.

Firstly, we modelled the freshmen's attributes, perceptions, experiences and performance factors. Fig. 5 shows relationships among predictors and dependent variables in the architecture design process.

For the freshmen architecture students, a creative engineering design performance as desired behaviour is not well supported, since scaffold active learning framed with social-cognitive theory seems to be rather rare. The two dimensions of CEDA Fluency and Flexibility are not statistically explained by the influencers of personal factors

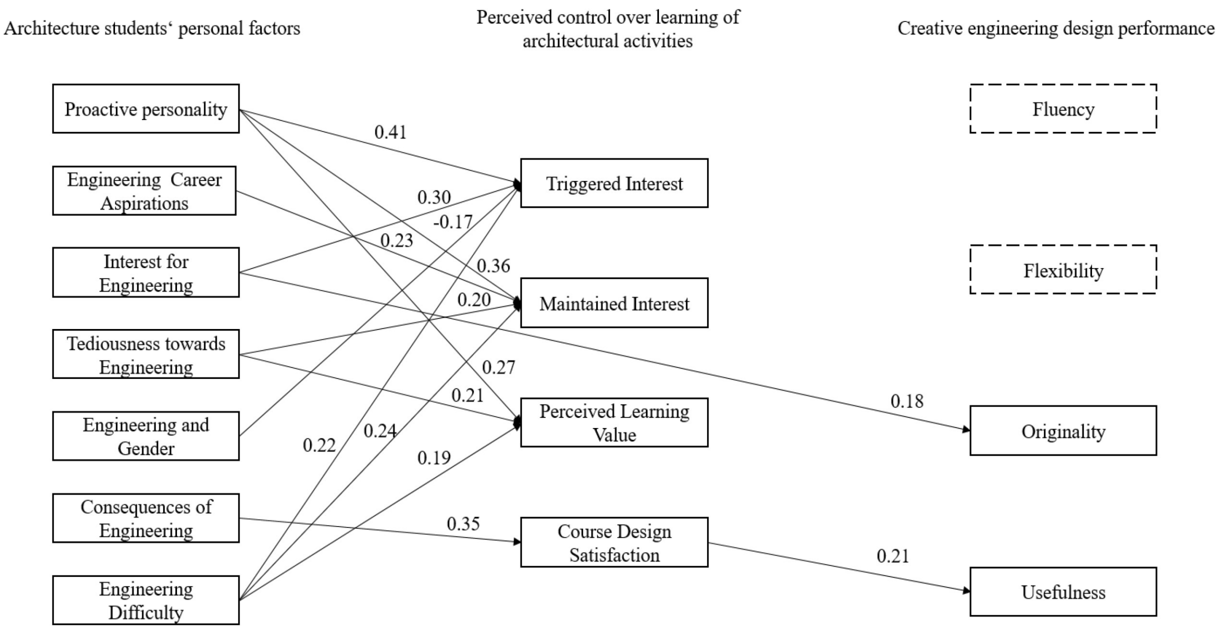

Fig. 5. A model showing the relationships among freshman architecture students' personal factors, perceived control over learning, and creative engineering design performance with significant ($p < 0.05$) standardised regression coefficients ($n = 108$). Variables in dashed line rectangular were not significant explained ($p > 0.05$).

and perceived control over learning of architectural activities. It was also found that students' proactivity seemed to be the strongest positive predictor of situational interest and perceived learning value, while students' perception that engineering is a domain for men only decreased students' triggered interest for engagement in architecture activities. Students who have more resistance to engineering in general are more likely to pursue architecture tasks and estimate value of learning at higher levels.

Interest for engineering was found to be a direct predictor of originality of products or designs, while awareness of consequences of engineering on our lives and environment strongly predicts students' satisfaction with the course of architecture subject matter. Students who perceived engineering subject matter as difficult were more likely to put more effort in design tasks and consequently have rated their learning value higher. It appears that freshmen in vast number of cases, as extrinsically motivated students, use external regulation especially at performance-oriented learning tasks. It is expected that self-efficacy and social cognitive learning increase over the course of the semester [22] and over the years of the study tend to become more autonomously motivated, with integrated regulation when understanding the value of learning activity [27, 34].

For senior architecture students, it seems that a social-cognitive framework supported by self-determination theory is well-developed during their study as shown in Fig. 6. Creative engineering design performance is markedly explained and many predictors were found with both direct and indirect influence.

The strongest positive predictor was found in a proactive personality which significantly ($p < 0.05$) and strongly ($\beta > 0.24$) predicts students' control over learning of architecture subject matter, divergent thinking expressed with fluency and originality of designs, and usefulness of design/products as the most important dimension for engineering creative performance. Moreover, proactivity while mediated through triggered interest also predicts flexibility of designs.

The most negative predictor of creative engineering design performance, a tediousness towards engineering was identified, especially when divergent thinking was needed to find more ideas and solutions, to use diversity of material, and to identify current and potential users and when convergent thinking was present where an optimal solution to research problem needed to be found. Rather, it seems that students used existing ideas, concepts from existing engineering products or systems which they have learnt or been exposed to throughout the study.

A very interesting path was found, namely, while freshmen develop their self-efficacy through emotional and psychological states and need confirmation in well designed and effective learning environments to decrease stress with the assigned tasks thus enhancing creative design performance, senior students develop their self-efficacy through

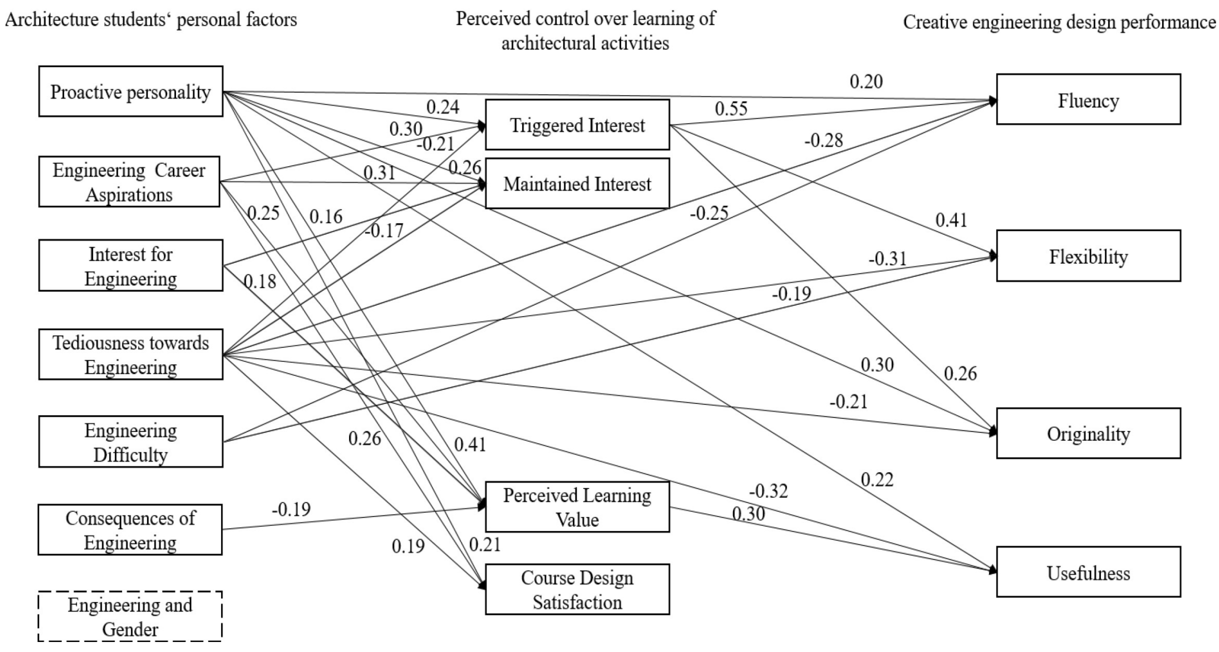

Fig. 6. A model showing the relationships among senior architecture students' personal factors, perceived control over learning, and creative engineering design performance with significant (p<0.05) standardised regression coefficients (n = 98). Variable in dashed line rectangular was not significant explained (p > 0.05).

mastery task performance, from vicarious experiences, while seeing peers working on tasks and when persuaded by role models or teachers that they are capable of mastering an assigned task. Thus, senior students are more likely put more effort and persist in activity when problems arise. Students with higher level of proactive personality will utilise this verbal persuasion to develop their own self-efficacy and will be better not only at problem solving but also at problem finding, looking for new opportunities and challenging the *status quo*, despite the fact that they are exposed to a plethora of existing products and processes. Thus, more likely they are able to create more original and useful designs, also for future uses.

In contrast with them, senior students who have perceived learning value of architecture and design activities to be higher are more likely to be capable of creation of very useful designs, considering not only consequences of engineering on our lives but also a broad picture rather in an interdisciplinary framework, where technology and engineering impacts on social, economic and natural environment are considered.

5. Discussion

This section presents answers to the questions inferred from data collected with two questionnaires and a test.

5.1 RQ1: What is the relationship between architecture students' proactive personality and attitudes towards engineering and their perception of the learning of architecture subject matter for freshmen and senior students in the framework of social-cognitive theory?

Freshmen's proactive personality significantly predicts their triggered and maintained interest, and their learning achievements in design work are perceived to be higher which is consistent with findings of [1, 28, 31]. A very interesting category of attitude was revealed, namely students' tediousness toward engineering in general, positively predicted maintained interest and learning value of design activity. This might be due to external regulation of the learning process with controlled motivation, which can explain this finding confronted with findings of [43]. Probably they are less competent in general engineering knowledge; therefore, these students have more resistance to the tasks, but they design for marks and credits to pass the study year. In freshmen, a perception of difficulty of engineering plays a significant role in prediction of situational interest and learning value. These students are more likely externally motivated, thus a learning environment with positive topic emotions enhances their learning and develops their self-efficacy which is consistent with [22] and [23]. It seems that students who are aware of the consequences of engineering develop their self-efficacy rather in emotional and psychological states where learning environment can enhance their creative ability and they can create more useful products or designs.

Senior students' proactive personality is a strong positive predictor with more value in situational interest, learning value and course design satisfaction. It seems that higher the level of proactivity stronger is its predictive value in perceived control over learning of architecture activities. Expectedly, students' tediousness towards engineering predicts negatively their situational interest, especially if students practice design work as problem-driven or solution driven cognition type [22]. Senior students' aspirations in engineering careers positively and strongly predict situational interest, with higher level of learning value and satisfaction with the learning environment design. Students' awareness of consequences of engineering might be helpful especially for freshmen, while senior students during the study develop a bigger picture of different environmental influencers and their learning value focused only on engineering can decrease.

5.2 RQ2: What is the relationship between architecture students' perceived control over learning of the architecture subject matter and their behaviour in terms of creative design performance for freshmen and senior students in the framework of social-cognitive theory?

Freshmen's creative engineering design performance is not significantly affected by their situational interest, while freshmen's perceptions over own learning of design activities seem not to be developed yet. It seems that freshmen practise design work in a rather reproductive way as information-driven where students do not have the chance to understand the value of activity and internalise it [15, 26, 43]. They rely rather on cognitive fixation, but this can decrease creativity [36]. Freshmen who felt comfortable with the learning environment scored higher in usefulness of designs.

Senior students' creative engineering performance is largely explained by their perception of their learning in architecture activities. Triggered interest significantly predicts fluency, flexibility and originality of designs, while they are more likely to improve self-efficacy through mastery goal orientation, observing their peers at design work, and are rather encouraged to complete the task by their teachers. Students at mastery performance gained deep engineering knowledge and acquired more creativity and engineering skills at solution-driven approach to design work. Those students also scored higher at design usefulness scale. It could be that rational and conscientiousness students during design work improve their self-efficacy and thus can do more creative engineering designs [9]. Moreover, the senior students also perform markedly better in decision-making where convergent thinking is required and in collaborative learning environment where high task variation and mental models divergence are required to transfer of team learning, what also confirms findings of [49].

5.3 RQ3: Do architecture students' proactive personality and attitudes towards engineering directly predict creative design performance for freshmen and senior students in the framework of social-cognitive theory?

Freshmen students' proactive personality seems not to directly predict their creative engineering design achievement. Only the students' interest for engineering subject matter significantly predicts originality of designs and could be associated with their grade point average as a measure of academic achievement [5].

Social-cognitive learning of engineering design at the senior architecture level is well-developed. Proactive personality of students directly positively predicts their idea generation and original and useful designs or solutions. It seems that proactivity overcomes cognitive fixations generated during the study [32, 36]. Students' tediousness towards engineering can create resistance to creative learning since the senior students have been exposed during the study to a plethora of design solutions where a prevalence of design fixation is a significant concern which might decrease fluency, flexibility, originality and usefulness of designs [32]. Similar disposition has been detected at the students' perception of engineering study difficulty but probably only for less effective and creative students' who failed at idea generation in quantity and flexibility.

An engineering view on design reflects 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" [47, p. 104] and as an educational approach, design and design thinking has been selectively applied to engineering and architecture curricula over a wide range of disciplines [49]. The findings from some recent studies suggest that engineering design and design thinking are not comprehensibly covered [49] where students from mechanical engineering have a markedly higher expectation to engineering design during their study [46, 49] but environmental and civil engineering students have higher expectation to help others through the career [49] and this reflects in more emphatic design approach that design thinking requires [49, 50]. It seems that architecture students with developed ability for engineering design thinking to solve architecture problems more likely can find it challenging to collect the users' input during the problem-solving process and the solutions generated from the users' concerns and needs were more diverse, more imaginative and more feasible [50]. Since the architecture and civil engineering are very intertwined and they are involved in planning and designing structures, where architecture focuses more on spatial functionality, aesthetics and functionality to design itself while civil engineering concentrates on the structural elements of the design, it was expected that at environmental problems architecture students demonstrate a higher levels of design creativity in their approach to solutions (fluency and flexibility of conceptual embodiments, feedback seeking, integrative thinking, proactivity, openmindedness, collaboration, experimentalism) also very known behaviour for civil and other engineering students [49, 50]. Moreover, the education level of architecture students was found a stronger source of variation for assessed creative engineering design ability than disciplinary differences and method of implemented design-based learning [46]. In comparison with some recent studies [46, 49], it was also found that creative engineering design performance scores of senior architecture students were higher than their counterparts, while aforementioned across engineering disciplines studies revealed that design thinking ability of senior students can be lower. It might be that senior students in majority of lessons behave in a more algorithmic way when using rules, laws, and equations and tend to rely on existing products and solutions and see no added value to new knowledge and skills acquired. The present study revealed that senior architecture students have developed through study more feedback seeking, critical thinking and experimenting skills using user-centred design lessons and divergent thinking to reduce cognitive fixations developed in other lessons. Moreover, it seems that senior architecture students through several interactions with social, economic and natural environment during their study developed more empathy with final users and these interactions have contributed to successful design-based learning.

6. Limitations and Implications of the Study

First limitation of the study is a selection of freshmen and senior students only as a one-shot study.

The authors assumed that cohorts of student are comparable, based on their grade point average. More insights can be provided if we follow a cohort from the first year of the study to graduation.

Second limitation is that the scope of the study considered creative engineering design as a measure, while some measure of general creativity will be useful at mapping social-cognitive learning of freshmen.

The study offers several implications for architecture education: (a) curriculum change based on problem- and solution-driven design work, (b) creative engineering design model for assessment of architecture student design solutions, and (c) a social-cognitive framework for creative design built to enhance innovation learning for architecture students and for organisations to develop design-based innovation learning.

Moreover, the present study has several implications also for vast of engineering disciplines: (a) an effective user-centred design process can be implemented to improve design-based learning through the study, (b) the developed motivation model can be used to implement design-based learning goals, strategies and influencers that led to decisions, self-regulated learning and satisfying learning experiences, and (c) a social-cognitive model developed in this study can be used to cope with current interdisciplinary design problems, where phase of the empathy with final users of design products can be strengthen. A transfer of the developed model from architecture might be helpful to improve engineering students' creativity, innovativeness and finally a readiness for career in engineering.

7. Conclusions

The contribution of this paper is the building of a social-cognitive framework for creative engineering design of architecture students. The findings from our study suggest that student's proactivity is an essential personal characteristic, one that significantly predicts creative design ability and can and should be supported and developed through the solution-driven design process. Moreover, several cognitive fixations during the study can reduce students' creative design ability, thus, a development of problem- and solution-driven design skills is as important as content learning and should be scaffolded over a study program so that skills are built and practiced throughout. Moreover, practising solution-driven design work increases student self-efficacy while they master their tasks and acquire vicarious experiences across the study from first year to graduation, but it is necessary to have a soft transition from information- and knowledge-driven design work in younger students, where self-efficacy can be developed through positive topic and learning environment emotions and perception, to senior students. Senior students are more likely to produce higher quality engineering design solutions where they utilise positively and proactively their exposer to plethora of existing engineering products to turn them into original and more useful designs.

The creative engineering design assessment reported here could complement educational programmes since the tool measures originality and usefulness that are core components of creativity in architecture and engineering domains. Using a social-cognitive model for creative design work can enable students to develop their talents as future innovative architects. Abilities to create and innovate appear to be important factors in improving the quality of education in the 21st century and a key characteristic of a high-quality education system that is able to implement contemporary technology- and engineering-based educational designs.

Further studies could also explore the self-efficacy of different cognition-types of design work measured through design performance where commercially available solutions do not yet exist.

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