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Effective schematic design phase in design process

Samira Mohamed Ahmed Abdullah[1,2] · **Naila Mohamed Farid Toulan**[1] · **Ayman Abdel-Hamid Amen**[2]

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Abstract
Design thinking is a way to create solid designs that responds to design problems and solve it in a creative and suitable way. However, it is not widely recognized in architectural education pedagogy in Egypt for undergraduate. Despite being very efficient in several business avenues but not in architectural pedagogy. So, this paper aims to spot the light on design thinking and the possibility of its usage in design process to help students have a successful architectural project that solves the design problems and face the site challenges through the use of visualization design thinking tool. Where students face a challenge in translating the verbal language of their collected data in the research phase to the architectural language in the schematic phase. There is a recognized gap between the research students perform in the beginning of design project and the schematic designs that students deliver. The study proposes the possibility of using visualization as a tool for design thinking to have a sufficient and successful schematic design phase. The study will explain how students could apply design thinking in architectural design to benefit from their research phase in their schematic design. Moreover, come up with solutions and variable ideas using the tools of deign thinking as a way for helping in delivering design problem solution and have a more effective schematic design. At the end of the research paper the study concludes how the students can use visualization tool to translate the verbal language to architectural language and the possibility for using design thinking. That to help students realize the importance of analysis phase in synthesis. The research follows descriptive method and quantitative analysis where first the descriptive method is used in illustrating design process and design thinking. Then the quantitative analysis in the experiment is done followed by a survey to prove research problem and help in proposing the solution.

Keywords Design thinking · Design process · Schematic design · Problem solving · Visualization · Analysis and synthesis

✉ Samira Mohamed Ahmed Abdullah
samira.abdalla@bhit.bu.edu.eg

[1] Architectural Department, Faculty of Engineering, Cairo University, Giza, Egypt

[2] Architectural Department, Faculty of Engineering, Benha University, Benha, Egypt

Introduction

To lead a successful architectural design the designer will need to go on and deal with very complicated and complex challenges that will face him during his design process. This requires the designer to be flexible and to have the required design skills and technical knowledge and sufficient information to go on with a successful project. From the most important skills that the designer must have is the creative thinking. Whatever faces the designer there must be that soul of having the power to think and identify the problem to come up with a solution. As, explained by Ghonim (Ghonim, 2016) design is an activity that requires to think out of the box and have creative ideas that create new outputs. Design stimulates the human brain to produce creative ideas and be more productive.

Students in the architectural design studio often grapple with a significant challenge which is effectively connecting their research endeavors with the practical application of findings in schematic designs. One central issue lies in the seamless integration of theoretical knowledge acquired during research into tangible design solutions. Developing the skills to translate abstract concepts into actionable design elements proves to be a hurdle for many students. The struggle extends to understanding the direct influence of research outcomes on design decisions, leading to a potential disconnect between theory and practice. Here lies the importance of performing this study.

Literature review

Design thinking

Design thinking is seen as a way to solve problems that face architects in their designs and helps in finding creative solutions (Goldschmidt & Rodgers, 2013). Willemien Visser mentioned that design thinking is for designing activities in a cognitive way that designers use and apply during their design process. So, to be able to apply design thinking, there are main steps that designers apply to achieve their target for solving design problems which are (Tymkiewicz & Bielak-Zasadzka, 2016):

- Designers need to first identify the problem that needs solution.
- They need to identify the user's needs, which will be mainly through surveys or through the client if he is the direct user.
- After that, the designer needs to brainstorm his ideas that should solve the design problem
- Then comes the phase to evaluate the ideas and put them into practice to get the best solution out of them, which in return gives the door for using design thinking and helps in answering the research question.

There are two approaches for design thinking discussed as follows:

- Vertical design thinking

  Vertical thinking is mainly concerned with evidence, proves and for generating ideas that result from analysis and information gathering (Hernandez & Varkey, 2008). The designer in this approach puts an assumption or what is called as an initial assump-

tion upon which he builds the design and take his decisions. This initial assumption or hypothesis is fixed and is known by the fixation effect (Eissa, 2019).

In this type the designer goes deeply and adheres to his solution and tries by all means to prove and validate it. He refuses going to other solutions or to even generate other new ideas than his initial assumption or idea. He tries making it work by all means which in return shows the weakness of this approach as this kind of thinking and rigidity is not acceptable in design process. (Goldschmidt & Rodgers, 2013).

- Lateral design thinking

  This approach is the opposite of vertical thinking. Here the designer tries to generate and come up with many ideas and creative solutions. The designer in this approach never adheres to that one single initial assumption, as there is always room for other ideas and alternatives. Which is known as a breaking out from the initial assumption, which is also known as frame of reference (FR). that opens the door for creativity in the design process (Akin & Akin, 1996).

  When the time comes for coming up with solutions for design problem the design maps show up. That helps the designer throughout his journey to go through the phases for design solution. Although the vertical thinking is only concerned with adhering to one solution and refuses other alternatives, when thinking deeply it is found that the analysis and synthesis processes are mainly relying on this type of thinking (Goldschmidt & Rodgers, 2013). Markus/Maver design map is a good example for that as this kind of map mainly discusses the design process and its phases. As Lawson mentioned in his book "how designers think" this map takes the design process starting from analysis phase and briefing it then goes to synthesis phase following it with Evaluation then decision making (Lawson, 2005).

In this design map the first step as mentioned before is data gathering then analysis. through that the designer understands the requirements and needs of the client and identify his program and the understands the design problem (Lawson, 2005). That requires producing design solution through which the designer identify objectives and targets. After the analysis that in which the problem is clearly defined and the objectives and targets are set, comes the synthesis phase. that solves the design problem through an architectural drawings solution (Nazidizaji et al., 2015). At the end the designer will have the solution presented in architectural drawings that are ready for the evaluation phase, were it must meet the needs and objectives that accomplish the targets that were set in the analysis phase.

However the design process is always found to be backward and forward as it is repeated in iterations for the reason of modifying. This will cause returning back to the synthesis phase where the design should be modified. That in return may require more analysis as there will be a change in the decisions taken in the design (Eissa, 2019).

Design thinking tools

Design thinking tools are techniques and methods employed in the design thinking process to encourage creativity, collaboration, and user-centered problem-solving. Design thinking tools can be effectively integrated into the architectural design process to enhance creativity, collaboration, and problem-solving. Integrating design thinking tools into the architectural design process encourages a holistic and user-centric approach. It helps architects generate innovative solutions, consider diverse perspectives, and refine designs based on user experiences and feedback (Plattner et al., 2011).

Visualization plays a pivotal role in the architectural design process, serving as a potent design thinking tool that aids architects in conveying ideas, exploring possibilities, and refining concepts. According to Cross, visualization is integral to the design thinking approach, allowing designers to externalize their thoughts and collaborate effectively (Cross, 2011).

In the context of architectural design, Moggridge emphasizes the power of visualization in translating abstract ideas into tangible representations (Moggridge, 2006). From early sketches and hand-drawn diagrams to sophisticated digital models using tools like SketchUp or Revit, architects leverage visualization to communicate spatial relationships, materiality, and the experiential qualities of spaces.

Another tool for design thinking is journey mapping which is valuable in understanding and expressing the user experience within the designed spaces. Brown suggests that journey mapping is particularly effective in uncovering hidden aspects of the user experience (Brown, 2008). By mapping each stage of a user's interaction with a space, architects can identify critical touchpoints and areas where improvements or enhancements are needed. Journey mapping involves creating visual representations of users' experiences as they navigate and engage with different elements of a space. This technique is emphasized in the human-centered design processes outlined by IDEO, where architects use journey maps to gain insights into user behaviors, pain points, and moments of delight.

Mind mapping is a versatile and creative design thinking tool that finds practical application in the architectural design process. It serves as a visual technique to organize thoughts, generate ideas, and explore relationships among various design elements. According to Cross, mind mapping is an effective mean for designers to externalize and structure their thinking (Cross, 2011).

Role of design thinking in design process

The designer's brain acts as an archive where he stores information and pictures of what he collects and analyzes. Therefore, thinking in its basic form is a mechanism processed in the designer's mind relying on the information gathered and pictures he has seen (Cho, 2017). However, basic thinking does not acquire much effort, but it is considered as an important part of the thinking process done in the design process. As all information is proceeded in this stage from that collected in research, gained through lifetime experience and from designer's cultural background. Therefore, it can be said that this fundamental and initial step of thinking can lead to coming up with a solution, however it is not final but accepted. (Taneri & Dogan, 2021).

So, Design thinking can be involved in all design processes from problem solving to decision making as follows and shown in Fig. 1 (Lawson, 2005):

- *Problem solving* in this step the problem must be clearly defined and identified. from the information collected in research. That's to find out how to respond to the problem reasons and solve it in a way that responds to the needs and requirements of the project. Which will result in finding creative solutions and ideas for different solutions.
- *Design*: this part includes the trial of conducting a design solution and proceeding it in a visual form and so developing while in process of designing self-criteria for evaluation before finishing the work.

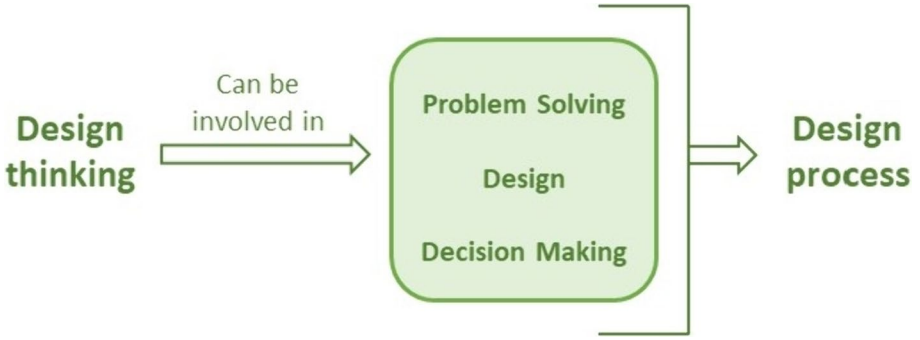

Fig. 1 The design process where design thinking can be involved, *Source*: Lawson (2005)

- *Decision making* here the designer has to come up with the previously generated design solutions and judge them visually and see their effect on the final solution however, their decision shouldn't rely on personal taste.

Design process

The design process that Darke wrote about is considered to be the primary generator. She said that conjecture analysis can replace analysis and synthesis. She illustrated that by saying that the primary generator is a group of related ideas that helps in generating the solution (Darke, 1979). So, it helps the architect to focus on a group of objectives to define and know the starting point for his design (Smith & Schank Smith, 2014).

However, Schön gave another practice for design process, which he named as the reflective practitioner (Schön, 2017). He explained the RF as a reflective practice through it architects with experience are aware of the knowledge and the past experiences they gained from different projects and what they learnt from it (Daalhuizen et al., 2014). Besides what architects face from forward and backward in the process as they frame and reframe the design problem more and more again which in return affects the design decisions (Schön, 2017).

However, the design process is known for its main 4 phases that any architect must pass through to have a successful project at the end. They must be done with specific arrangement and relate to each other. These four phases are analysis, synthesis & evaluation (which is divided into (design development and construction documentation)) (Smith & Schank Smith, 2014) as shown in Fig. 2 and stated as follows:

- *First*: *The research phase* (the analysis phase) is the first stage where data is collected. Everything about site is known and clear. Besides identifying and understanding the design problem and challenges (Abowardah, 2016). The designer in this stage determines the problem and know the goals which in turn requires to state clear objectives. Therefore, the methodology is set to achieve the goals to come up with a good design solution that responds to the design problem (Ulug, 2010).

Fig. 2 Design process, Source: Smith and Schank (2014)

- *Second*: *synthesis phase* in this stage the designer usually comes up with solutions for the design problem and where ideas are translated to sketches. The designer usually starts to use the conceptual approach to state his idea for the solution (Daalhuizen et al., 2014). This stage is considered to be the problem-solving phase in an architectural language.
- *Third*: *the design development* is where the designer starts to refine his drawings. The ideas start to take a clear and more defined shape in serving the solution in a proper architectural language(Ulug, 2010). In this stage the designer starts to evaluate and see clearly his design and how it responds to the design problem.
- *Fourth*: *The construction documents* are more accurate than the previous. its where the location, dimensions, materials, sections, elevations and all other required building specifications are presented.

Design learning in design process

Understanding how students act and go about their architectural design work in design studios is important for making architectural education better. Recent studies have investigated this in detail, giving us useful ideas about how to teach and create a good learning environment in design studios. These studies focused on different parts of the design process, including the early design stage. They checked how things like doing research, different ways of learning, and using technology affect how well students do (Hettithanthri et al., Nov. 2023).

The Learning by Design method lets students dive into designing and suggesting scientific investigations in a stronger way. However, many design approaches usually start with giving a specific design challenge. This can limit students from starting with their own questions that are worth investigating scientifically (Mehalik et al., 2008). As mentioned by Mehalik, Doppelt, and Schunn the system design-based approach is good for helping students learn design better. As, they learn to answer the questions that most of them ask themselves at the beginning, which is "why do I need to do this or why do I need to know this". So, this helps students to understand their needs in the design and understand better how to deliver a better design (Mehalik et al., 2008). As mentioned by Gómez Puente that Design based learning DBL is an educational approach that helps in generating innovative solutions. So, through using it educators can help their students in the learning process to gain domain specific knowledge and the thinking activities relevant to the purpose of the solution (Gómez Puente et al., 2013).

Many studies have investigated how different ways of approaching design impact how well students do in their studies. In one study, they found two main ways students go about it: one where they focus on the big idea (concept-driven), and another where they use research a lot (research-driven) (Demirbaş & Demirkan, 2003). The research-driven way, which involves clear steps and guided exploration, led to better results for the students in the study. This suggests that having a clear plan in the design studio can help students handle the challenges of the design process and do better in their studies. Research has consistently highlighted the challenge of seamlessly integrating research findings into schematic designs within the architectural education context (Hosny et al., 2023). The transition from the analytical phase, where research is conducted, to the creative synthesis of design solutions can be a complex process.

Previous researchers have also investigated how using technology in the design process affects students. One study pointed out that bringing in digital tools and software during

design can make students better at imagining and showing their ideas (Mirmoradi, 2023). This is especially important in the early design stages when clearly explaining spatial ideas is crucial. Even with all the progress in technology and how educators teach, students continue to find it hard to turn their thoughts from words into architectural drawings. This difficulty happens because design ideas are often abstract, demanding good technical skills, and there are challenges in expressing these ideas clearly through pictures (Nabih & Hosney, 2022). As a recurrent issue faced by students is the translation of verbal ideas into visual representations. This challenge arises as students struggle to articulate their conceptual understanding verbally and then face difficulties in transforming these ideas into architectural drawings.

Demirkan highlighted how it's crucial to blend research and critical thinking with the usual design techniques (Demirbaş & Demirkan, 2003). This method, shaped by research, urges students to dive deep into analysis, consider various viewpoints, and create inventive solutions. When research becomes part of the design process, educators can shape students into architects with a broad skill set, ready to make meaningful contributions to their field. The balance between creativity and practicality emerges as a central theme in the architectural design process. Some students may prioritize aesthetic aspects over functional requirements, leading to designs that lack practical viability.

Schematic design phase

Schematic design is the phase where the designer starts to translate his thoughts and ideas into sketches. It is where the program turns into the architectural language. The designer chooses the conceptual design approach to approach his design (AIA, 2007).

Major variables affecting design

In this stage, the designer starts to deal with the design problem in practice. Therefore, there are important factors that affects design process and decision making for design solution that needs to be taken into consideration stated as follows (AIA, 2007):

- *Program*: The first factor that will affect the project is the program the client requires to be applied to his project. Usually, the program highly affects the spaces and the function. The designer will have to set his objectives according to the project program, as every program is unique to a specific project.
- *Codes and Regulations*: When going deeply into design and starting to take action the designer will have to put in mind a very important factor that would simply destroy the whole project when it comes to reality. This factor most important factor is codes and regulations that simply supports safety and minimal land use (Djabarouti & O'Flaherty, 2018). The designer must follow the code and obey the regulations. For every country and even every area, there are codes and regulations that most designers consider as determinant in design.
- *Site*: Then comes the site of the project, which has a great effect on the influence of the building design. There are physical factors in site, which will affect the design decisions like the topography, size and the geographical technical issues that will form challenges. There also could be any existing structure or some important environmental factors that should be taken into consideration. It is also very important to give a great attention to the surrounding environment. The context should have a great impact

on the design's identity. As any other built structure should feel homogenous with the other built environment. It will affect the form, concept, color and material (Daalhuizen et al., 2014). Most of projects requires dealing with existing structures that should be combined with the project.

- *Building Technology*: Building technology is important to put into consideration when going with building design. The designer should respect the available structure system and the budget that will constrain the technology. Which may affect his idea if it is something related to structure and solving a problem related with area and size. However, every function or module for a specific building should have a criterion such as hotel is different from a theater or an office building (AIA, 2007).

Primary steps in schematic design

Despite constrains and factors mentioned above that the designer faces in the schematic phase, he would go through primary and initial steps that should include a fixed process, That is illustrated as follows (Djabarouti & O'Flaherty, 2018):

1. *Analysis*: which results the identification of the design problem
2. *Synthesis*: it's the form of transferring the analysis into conceptual idea and proposing some solutions and setting objectives to achieve goals
3. *Refinement*: here the concept and idea is refined and the design solution is much clear
4. *Documentation*: the architectural project is in the stage where the architectural drawings are ready to be delivered.

Design thinking effect on schematic design phase

Design thinking can be illustrated as the knowledge that is understood and gained through which the designer will be able to understand the design problem. Then he will be able to think of the solution in a more reasonable way. That will result in a solution for the design problem that fulfils all the objectives set (Tymkiewicz & Bielak-Zasadzka, 2016).That will help in answering the research question RQ in return. Therefore, for the design thinking to take place there should be three steps to be done illustrated as follows:

- *Analyzing*: the first and initial step is helping students to translate their ideas into drawings and visuals. In addition, it is very important to put assumptions at the beginning about the design problem and to classify all the collected data. Then they need to learn to know the objectives and know how to come up with ideas to solve problems. So, it's important to build upon old designs and always to develop ideas regularly (Lawson, 2005).
- *Criticizing*: it is very important for designers and students at the very beginning to know how to criticize their works. The work needs to be assessed by its creator even before another peer or educator assessment (Mahmoodi, 2001). So, this will help in developing the skill to find solutions and develop it. Therefore, it will make it easy to judge and evaluate the solution. However, students still cannot do this perfectly as for the lake of qualifications compared to a skill architect.
- *Comparing*: after that comes the comparison as the student or the designer needs to develop the skill of identifying reasonable solutions that responds positively with the

design problem and solves it. That to be able to measure the success of the chosen solution. This will enable them to identify their thinking process.

However along with design thinking comes creative thinking that was proposed by Mahmoudi (Mahmoodi, 2001) which is mainly related to Visualization through the initial thinking and visuals that the designer develop in mind while subjected to design problem in the design process and how he deals with it which will help in answering the RQ in return. However, creative thinking is like design thinking in relation to identifying the problem and coming up with the solution. It differs in steps as it includes synthesis, elaborating and imagining in the design process. That are illustrated as follows (Cho, 2017):

- *Synthesizing*: In this step, the student will need to be introduced to design types and thus know how to implement them that will in turn help them to generate solutions. When doing this it will be easy for students to apply the design strategy for the selected type to test the design idea.
- *Elaborating*: students need to learn not to stuck to their initial ideas and develop them. Here comes the second step of elaboration. In this step, the student should be able to expand his thoughts and modify the basic ideas. This will enable the student to understand better the ideas of others.
- *Imagining*: finally, students have to imagine the response to the design problem. That has to come up with the solution. As it affect the problem and project.

Guilfords' thinking factors

In the realm of creativity and cognitive psychology, Dr. J.P. Guilford's groundbreaking work on the Structure of Intellect introduced a comprehensive model that identified key dimensions of human intelligence. Among these, four crucial factors: flexibility, originality, fluency, and elaboration, emerged as fundamental elements in understanding and assessing creative thinking.

Guilfords' thinking factors were used in many studies as a tool for measurement in the architectural design education for its importance and its significance in design thinking (Eissa, 2019). In Gero and Wells study (Gero et al., 2019) it was mentioned that Guilfords' thinking factors are used as a measuring tool for its significance in:

- Providing comprehensive assessment in creative thinking, as they cover the generation of ideas, adaptation, innovation and refinement of design concepts as described by Arnold (Arnold & Clancey, 2016).
- For the purpose of this study incorporating flexibility, originality, fluency and elaboration is crucial. As it forms a model with multidimensional nature of creativity. This approach is relevant in architecture where diversity and innovation are crucial.
- The Guilfords's model is a well recognized framework in the field of intelligence and creativity research as mentioned by Lewis (Lewis, 2005).
- The four thinking factors align perfectly with the principles of design thinking. As, They reflect the innovative and iterative nature of the design process.

The four factors give both qualitative and quantitative dimensions. This flexibility in assessment accommodates the diverse aspects of architectural design education.

Methods

Research problem

Design is seen as a process to achieve function through analyzing and proposing forms (Elizondo et al., 2010). Designers are required to produce a creative output (building) that does not only obey functionality but also goes with new concepts in form. That in return put them In front of challenges of technicalities. So, architects are required to give an interesting project that simply gives an appropriate solution to the design problem and an interesting physical building that provides the user with comfort and functionality in the use of every space of it (Snider et al., 2013).

For that, architects are supposed to various modes of thinking, and they face and handle many design approaches to come up with the required product. However, there is no exact way to guide the thinking process that will lead to a successful project from the early stage of having basic information about the project to the final step for the final product especially when it comes to architectural education in design studios. Therefore, this research mainly concentrates on the stage of linking the research phase with schematic design phase, which are widely known as (Analysis and Synthesis design phases).

Design solving problem in the design process must be concerned with design thinking as it is the initial step for having better design solutions (Abowardah, 2016). This will lead to prevention of modifications and backwards and forwards steps that happens always in the design process. It is found that Students often go to solving problems of the design mostly by experience and not through proper phases of analysis and synthesis phases.

Research questions

- How can students use design thinking as a tool that links research findings and schematic design phase in a way that leads to a successful effective schematic design phase?

Research aim

The research aims to prove the importance of using design thinking as a main linkage between research phase and schematic design phase, to help students have a successful design project. This will help students solve the design problem through using visualization design thinking tool.

Research objectives

- Exploring concept of design thinking and its approaches
- Investigating the Role of design thinking in the Design process.
- Analyzing the stages of the design process
- Examining the specifics of the schematic design phase within the design process
- Assessing the impact and influence of design thinking and its tools on schematic design phase.

Limitations

The study follows the conceptual design approach due to its perfect alignment with the architectural design education requirements and the architectural design project. The main focus when evaluating the students' works is evaluating their work through creative thinking. Which is measured using Guilvards four thinking factors. Through which the reasons for the unlinkage between research findings and schematic designs produced can be revealed. This will then help in answering the research question RQ.

Methodology

The research follows descriptive method and quantitative analysis where first the descriptive method is used in illustrating design process and design thinking. Then the quantitative analysis in the experiment is done Followed by an electronic survey to prove and show the research problem, then the proposed solution is discussed and stated.

Empirical study

The design project was carried out Through an academic year in the architectural design studio, faculty of engineering, Cairo University. Through Coordination with design instructors which started before the semester beginning. They were informed by the authors' idea. Besides being asked to participate in supervision. Students were asked if they wanted to participate or not. Students who agreed to participate were informed that the results and grades they score in this study will be only for academic research purposes and will not affect their original grades in course.

The Undergraduate students of architectural department were given a design project to work on through their usual architectural design studio. The project was about designing a school. The goal was to know how they would deal with the project from the very first beginning of collecting data to the phase of producing the architectural drawings. Mainly the aim of this project is to focus on how the students will deal with the transition from research phase to schematic phase and how they will work during schematic phase and develop their idea.

120 students took the project. They were asked to design a school on a land sized 18,000-m square in Aswan. The school has educational stages starting from kindergarten to preparatory stage.

The students worked individually starting from the first phase to the final stage. It was not allowed for them to work in groups as they do in the usual design studio. The Table 1 below shows the procedure and the duration of the experiment.

Measuring tool

Works of Students were evaluated according to Guilvard four thinking factors, which are Fluency, flexibility, originality and elaboration. Illustrated as follows:

Table 1 The table shows the experiment phases, requirements, and duration

Phases	Requirements	Duration
Analysis phase	Gathering information about site, understanding the project program, know design code for schools and define design drivers and finally to identify the design problem	Students were given two weeks to gather and analyze all the data
Synthesis phase	Provide design solution, developing adaptive design philosophy, developing schematic design diagrams, creating design concepts in terms of model, plans, sections, and elevations	The students were given 5 weeks where they submit weekly
Evaluation phase	Developing concept details in terms of the poster and model	They were given one week

- *Fluency*: means the number of solutions the student provides. The more solutions students provide in the early stage the higher is the ability to provide better ideas to work on. This gives high fluency.
- *Flexibility*: is the range of different domains the student proposals belong to.
- *Originality*: means that the student provides unique and new solutions to the design problem. The newer ideas and less repeated are better.
- *Elaboration*: here is the measure of levels of details as the more student thinks about details, like structure and material is the better.

Assessment questions were used to evaluate students' work relying on a rubric scale. To ensure the fixation criteria for assessment in any other design studio. The assessment was on the three design phases relying on conceptual design approach that is widely used in design education studios discussed as follows in Table 2 and Fig. 3.

The following Table 2 shows the assessment questions used for Guilvards thinking factors during evaluation of students' works in each phase (analysis-synthesis-evaluation).

The conceptual design approach was adopted for this study due to its perfect alignment with the architectural design studio requirements. Besides being a well-recognized adopted design approach in architectural design studios education. The 26 key elements for the conceptual design approach were followed in the three design phases (analysis—synthesis—evaluation) in the design process (Simitch & Warke, 2014) as shown in Fig. 3.

Analytical study

Overview

There were three stages in the project given: (Analysis-Synthesis-Evaluation). In each stage, there were criteria and points to measure and evaluate the performance of the students. One of these were the variables and to each variable was assigned a weight (% of the total mark). That was based on the importance of this variable (element) then the total mark representing the performance of every stage of the experiment and the total mark is then evaluated to quantitative measurement.

If the 1*total mark < = Student grade = < 0.85*Total mark is considered *Excellent*.

If the 0.84*total mark < = Student grade = < 0.75*Total mark is considered *Very good*.

Table 2 the following table shows the questions used in the assessment of thinking factors for the student works

Design phase	Thinking factors	Questions for factors assessment
Analysis	Fluency	How many distinct aspects or features of the site/context did the student explore during the analysis phase? Can the student provide a multitude of observations and data points related to the given design problem? In what ways did the student demonstrate the ability to generate a rich set of ideas based on their analysis?
	Flexibility	Did the student consider various perspectives and angles in their analysis of the site or context? How well did the student adapt their analysis methods to different aspects of the design problem? To what extent did the student explore diverse domains in understanding the project requirements?
	Originality	Are there unique insights or observations in the student's analysis that go beyond common expectations? Did the student introduce novel methods or approaches in gathering and interpreting data during the analysis? To what degree did the student offer original interpretations of the site/context?
	Elaboration	How thoroughly did the student explore and document the details of the site, considering both visible and hidden elements? Did the student delve into the intricate features of the site, providing a detailed understanding? In what ways did the student elaborate on the connections between different elements observed during analysis?
Synthesis	Fluency	How many distinct design concepts or solutions did the student generate during the synthesis phase? Can the student offer a variety of design alternatives that respond to different aspects of the analysis? In what ways did the student demonstrate the ability to generate a high quantity of design alternatives during synthesis?
	Flexibility	Did the student explore various architectural styles or design approaches during synthesis? How well did the student adapt their design concepts to different aspects of the site/context? To what extent did the student experiment with different spatial configurations or organizational structures?
	Originality	Are the design concepts offered by the student unique and not typical of conventional solutions? Did the student introduce novel architectural elements or spatial arrangements in their designs? To what degree did the student demonstrate originality in translating analysis findings into design concepts?
	Elaboration	How thoroughly did the student develop the details of their design concepts, considering structural and material aspects? Did the student delve into specifics such as interior layouts, circulation patterns, and material selections? In what ways did the student elaborate on the functional and aesthetic aspects of their design concepts?

Table 2 (continued)

Design phase	Thinking factors	Questions for factors assessment
Evaluation	Fluency	How many criteria or parameters did the student consider in evaluating their design concepts? Can the student provide a variety of criteria that encompass different aspects of the design problem? In what ways did the student demonstrate the ability to generate a comprehensive set of evaluation criteria?
	Flexibility	Did the student adapt their evaluation criteria to different design concepts or aspects? How well did the student consider various perspectives, including those of potential users or stakeholders? To what extent did the student demonstrate adaptability in their evaluative thinking?
	Originality	Are the criteria used by the student for evaluation unique and not commonly found in standard design evaluations? Did the student introduce novel considerations or perspectives in assessing the design concepts? To what degree did the student show originality in their approach to evaluating design solutions?
	Elaboration	How thoroughly did the student elaborate on the justification for their design choices during evaluation? Did the student delve into the details of how each design concept meets specific criteria? In what ways did the student elaborate on the connections between the evaluation criteria and the design concepts?

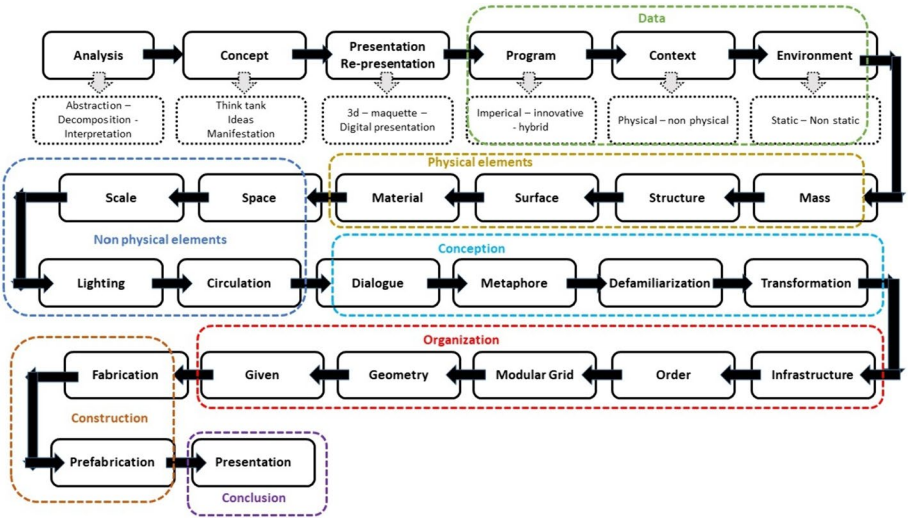

Fig. 3 The conceptual design approach with the illustrated 26 key elements

If the 0.74*total mark < = Student grade = < 0.65*Total mark is considered *Good*.

If the 0.64*total mark < = Student grade = < 0.5*Total mark is considered *Fair*.

If the 0.49*total mark < = Student grade = < 0*Total mark is considered *Failed*.

Then after knowing the total mark of each student at the end of each stage, the three stages were compared with each to identify the performance and the gap between each stage and the other. As, the frequency table is performed upon the final grade of each stage and finding the mean.

Steps of the analysis

1. Collecting the marks of each student in every stage and calculating the total mark. That's after assigning marks in each criteria based on the evaluation of the student performance in every criteria of measurement in an excel sheet.
2. Performing statistical analysis using normal distribution (bell curve).

$$(\text{pdf}) = F(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

where x: is the total marks of the students at the end of each stage, μ: is the mean of the total marks at every stage, σ: Standard deviation of total marks at every stage and square root of the variance

3. Then performing this analysis using python programming language and using google collab for running and compilation of the code.

Pseudo code of the data analysis

Step 1: extracting the total marks column of every stage in the excel sheet.

Step 2: calculating the mean, variance and standard deviation.

Step 3: performing the normal distribution 's pdf on the total marks of every stage.

Step 4: drawing the bell curve for every stage.

Step 5: visualization and comparison between the data.

Details of every stage

According to Guilvard four thinking factors the students are evaluated and each stage of the process where given weight in evaluation according to Guilvard. The grades weight are as follows for each stage, analysis was given 20%, synthesis is given 50% and Evaluation is 30%.

They are explained in detail as follows:

The four thinking factors were placed in a table to assess every student in each stage accurately. So their were 120 tables for each stage. There were 3 tables for each student for the three phases (Table 3, 4, 5).

Analysis

In the initial stage, through the analysis process, students were given two weeks to collect and analyze the data and they were required to deliver the following:

- Identifying the design problem with a weight of 20% from the whole phase.
- Drawing bubble diagram and understand the projects' zones with a weight of 5% from the whole phase.
- Drawing zoning for spaces and know the relations between different zones with 5% weight from the whole phase.
- Site analysis with a weight of 40% from the whole phase.
- Search design codes with a weight of 30% from the analysis phase.

Synthesis

After analysis, came synthesis stage where students were given five weeks to deliver this phase requirements through this stage, they were asked to deliver weekly submissions. They were asked to deliver the following:

- Ideas generation with 15% weight from the phase.
- Give solutions to the design problem with a weight of 17%.
- Show concept generation was given 23%.

Table 3 the evaluation table for analysis phase

Analysis (20%)					
Deliverables	Weight (grade)	Four thinking factors			
		Fluency	Flexibility	Originality	Elaboration
Identifying the design problem	20	Out of 20	Out of 20	Out of 20	Out of 20
Drawing bubble diagram and understand the projects' zones	5	Out of 5	Out of 5	Out of 5	Out of 5
Drawing zoning for spaces and know the relations between different zones	5	Out of 5	Out of 5	Out of 5	Out of 5
Site analysis	40	Out of 40	Out of 40	Out of 40	Out of 40
Design codes	30	Out of 30	Out of 30	Out of 30	Out of 30
Total	100	Sum of upper rows	Sum of upper rows	Sum of upper rows	Sum of upper rows

Table 4 the evaluation table for synthesis phase

Synthesis (50%)					
Deliverables	Weight (grade)	Four thinking factors			
		Fluency	Flexibility	Originality	Elaboration
Ideas generation	15	Out of 15	Out of 15	Out of 15	Out of 15
Solutions to the design problem	17	Out of 17	Out of 17	Out of 17	Out of 17
Concept generation	23	Out of 23	Out of 23	Out of 23	Out of 23
design decisions	20	Out of 20	Out of 20	Out of 20	Out of 20
Schematic designs	10	Out of 10	Out of 10	Out of 10	Out of 10
Refinement	15	Out of 15	Out of 15	Out of 15	Out of 15
Total	100	Sum of upper rows	Sum of upper rows	Sum of upper rows	Sum of upper rows

Table 5 the evaluation table for evaluation phase

Evaluation (30%)					
Deliverables	Weight (grade)	Four thinking factors			
		Fluency	Flexibility	Originality	Elaboration
Complete drawings	70	Out of 70	Out of 70	Out of 70	Out of 70
Project portfolio	5	Out of 5	Out of 5	Out of 5	Out of 5
Research performed	25	Out of 25	Out of 25	Out of 25	Out of 25
Total	100	Sum of upper rows	Sum of upper rows	Sum of upper rows	Sum of upper rows

- Show design decisions that were taken was given 20%.
- Create schematic designs was given 10%.
- Refine to deliver plans, sections and elevations was given 15%.

Evaluation

In this final stage students were required to deliver the complete project as follows:

a. Complete drawings were given 70%.
b. The project portfolio was given 5%.
c. The research performed was given 25%.

Feedback (survey)

At the end of the project after evaluation, an electronic survey was given. This survey was performed to know the students' feedback on the project given also to come up with reasons for the experiments result. The survey was divided to four parts explained as follows:

a. The first part is to measure the student's benefit from research phase done at the beginning of the process and this part was given a weight of 5%
b. The second part of the survey was to measure the impact of the research phase on the schematic design. This was given a weight of 25% from the total percentage of survey.
c. The Third part was concerned with the ideas generation and how students generate their ideas and what affects it most with a weight of 10%.
d. Finally, is the part concerned with the challenges that faced students in schematic design which is the most important part of the survey with 60% weight.

Results and discussion

The project given showed that the students failed to benefit from the research phase in their schematic design according to the evaluation relying on Guilvard four factors of thinking that were used in the evaluation of each stage from the three stages.

Analysis

In this stage the student's data showed excellence and proved their ability to perform the initial phase very good however, they failed to relate and connect it with the second phase (synthesis). The student's data results are as shown in Table 6.

Table 6 the results of students in the analysis phase

Grade	Excellent	Very good	Good	Fair	Failed
No of students	36	48	18	12	6
percentage	30%	40%	15%	10%	5%

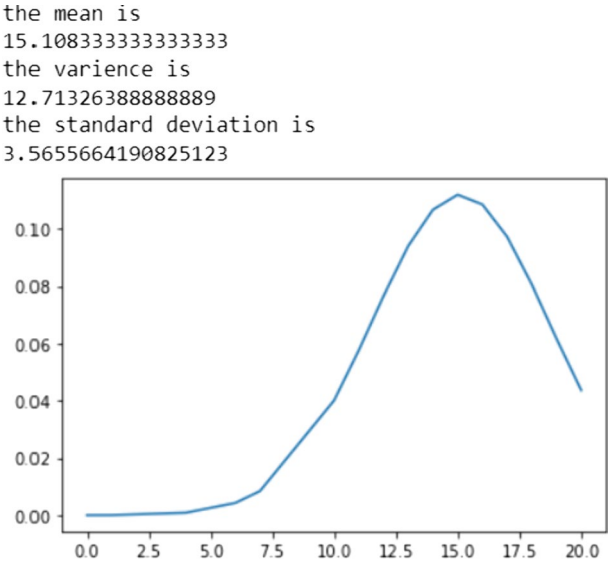

Fig. 4 Normal distribution curve for the analysis phase showing the results

The data are shown in normal distribution curve in Fig. 4 describing the result showing the mean and standard deviation where; $\mu = 15.10$, $\sigma = 3.5$ (Table 7).

Synthesis

In this stage the students showed failure as they were not able to perform this stage successfully according to the assessment using Guilvard four factors of thinking. As only 6% of the students scored between 85% and above in this stage. While more than 50% were between fair and failure Which shows failure. The results of students in synthesis phase are as shown in Table 8.

The data shown in table are described in normal distribution curve showing that students weren't good enough in this phase Fig. 5 according to Guilvard four thinking factors (Table 9).

Evaluation

In this stage, the students showed low results as only 12 students showed excellence and 13 student failed while 45 students were fair which is very critical. The results are as shown in Table 10.

From table above it shows the problem that faces students when evaluated according to thinking factors. They face challenges in synthesis phase, which in turn affect the evaluation phase, as there are no consistency between analysis phase and its application in synthesis. When they were evaluated according to Guilvard factors, which mainly concerns the design thinking as a tool in design process as a whole, and not only one part which is the schematic phase as usually done in design studios in design education. Figure 6 shows the students' performance in evaluation phase in normal distribution curve (Table 11).

This shows that students did not pass the experiment successfully. As only very few students scored 85 ≤ in the whole phases together in this experiment. That means that students

Table 7 the table shows the evaluation for the analysis phase for all students

Analysis (20%)					
Deliverables	Weight (grade)	Four thinking factors			
		Fluency	Flexibility	Originality	Elaboration
Identifying the design problem	20	15	13	13.5	14
Drawing bubble diagram and understand the projects' zones	5	3.1	3.4	3	2.8
Drawing zoning for spaces and know the relations between different zones	5	3.5	3.8	3.7	3.9
Site analysis	40	30.5	33	29	32
design codes	30	24.8	25.5	21.5	23
Total	100	76.9	78.7	70.7	75.7

Table 8 the results of students in the Synthesis phase

Grade	Excellent	Very good	good	Fair	Failed
No. of students	6	12	42	36	24
Percentage	5%	10%	35%	30%	20%

Fig. 5 Normal distribution curve for the synthesis phase showing the results

```
the mean is
28.716666666666665
the varience is
115.58638888888889
the standard deviation is
10.751111053695283
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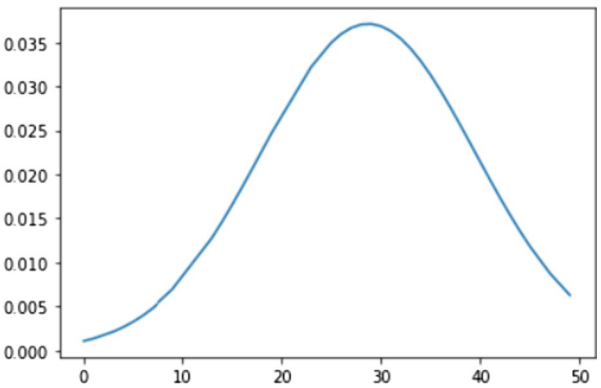

Table 9 the table shows the evaluation for the synthesis phase for all students

Synthesis (50%)					
Deliverables	Weight (grade)	Four thinking factors			
		Fluency	Flexibility	Originality	Elaboration
Ideas generation	15	11.8	12.2	11	10.2
Solutions to the design problem	17	11	12.3	11.5	12.3
Concept generation	23	12.5	11.5	10	10
Design decisions	20	9.5	10	10.5	11.6
Schematic designs	10	5.8	4.5	5	5.5
Refinement	15	7.5	8	7.5	8
Total	100	58.1	58.5	55.5	57.6

Table 10 the results of students in the evaluation phase

Grade	Excellent	Very good	Good	Fair	Failed
No. of students	12	24	26	45	13
Percentage	10%	20%	22%	37%	11%

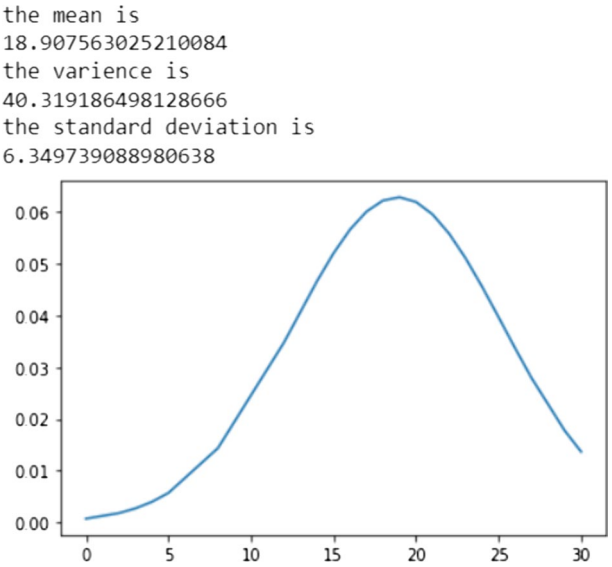

Fig. 6 Normal distribution curve for the evaluation phase showing the results

Table 11 the table shows the evaluation for the evaluation phase for all students

Evaluation (30%)					
Deliverables	Weight (grade)	Four thinking factors			
		Fluency	Flexibility	Originality	Elaboration
Complete drawings	70	42	42	41.5	45
Project portfolio	5	3.2	3	2.5	2.1
Research performed	25	18	19.2	16.5	17
Total	100	63.2	64.2	60.5	64.1

Table 12 General results of students

	Excellent (no. of students) (%)	Very good (no. of students) (%)	Good (no. of students) (%)	Fair (no. of students) (%)	Failed (no. of students) (%)
Analysis	66.7	57.1	20.8	13.0	13.9
Synthesis	11.1	14.3	48.6	39	55.6
Evaluation	22.2	28.6	30.6	48.1	30.6

lake to the skill of connecting the research phase to synthesis and produce a successful project that relies on a solid base of research and data analysis.

Therefore, the general results compared to each other in the three stages of the experiment were as shown in the following Table 12. Besides the bar chart and pie charts show the frequency of students in each phase of the experiment and there performance shown from excellent grade to failed in Fig. 7.

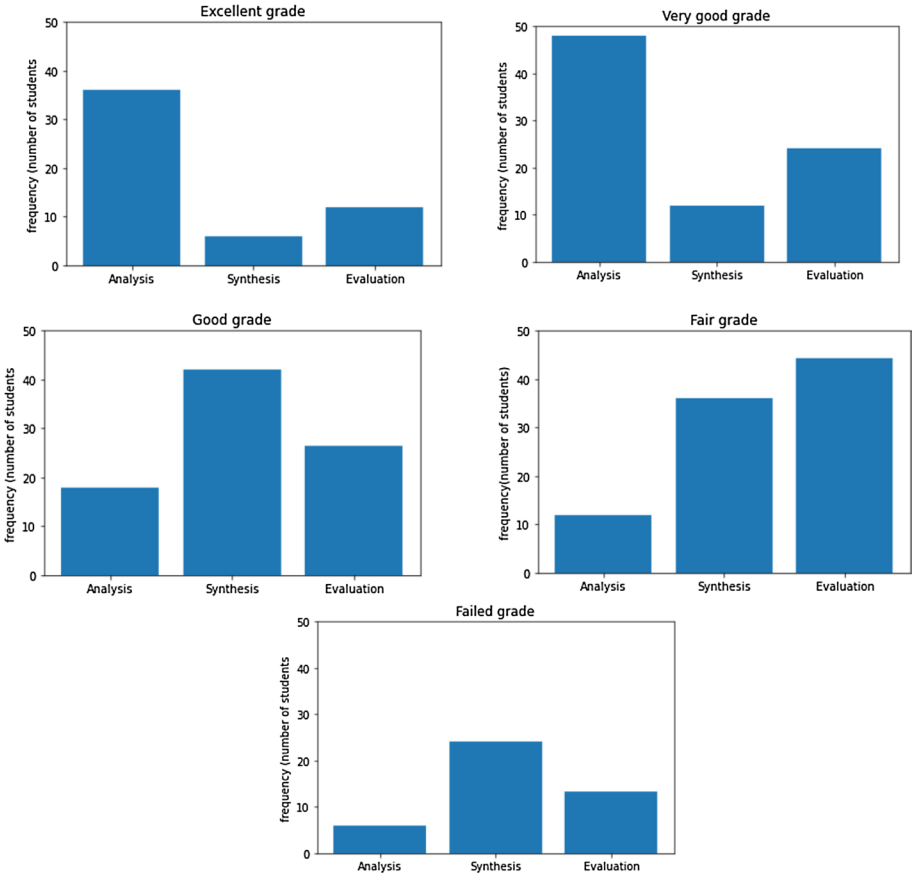

Fig. 7 The frequency of students' grades

The students showed a noticeable weakness in fluency and elaboration factors. These factors are related to visualization as a design thinking tool. As it was noticed that students have a problem when they try to translate their ideas to an architectural language and put their ideas on papers. That demonstrates the importance of introducing the use of visualization thinking tool to students to facilitate the transition of ideas and verbal language into sketches and architectural language (Table 13).

Survey

As seen from experiment, students didn't show a good result and so the survey was done to measure four important parts that would help in coming up with a result and a framework that would help students perform a successful design process. The survey was performed to measure four parts, first the benefit from research phase done at the beginning of the process. Second, the impact of research on schematic design. Third, ideas generation. Fourth, the challenges that faced students in schematic design. It showed the following result as seen in the following Table 7.

Table 13 the survey results

Surveys parts	Weight of each part in evaluation	Comments on each part
Benefit from research phase done at the beginning of the process	It was given a weight of 5%	40% of the students who agreed about the importance and benefit of research in other phases of design. Some wrote in comments that they go back to their design when they question anything in design code. While the major percentage of students did not find it useful in design process Where this part's results are: 22% Strongly agree 20% agree 45% neutral 8% disagree 5% Strongly disagree
The impact of the research phase on the schematic design	It was given a weight of 25%	More than 25% of students were agreeing on the impact of research phase and the analysis done at the beginning of the design process, especially in the part concerned with the bubble diagram and zoning Where this part's results are: 13% Strongly agree 25% agree 50% neutral 7% disagree 5% Strongly disagree
Ideas generation	It was given a weight of 10%	36% of students were with the first phase and its effect on their thinking. Moreover, on how they may get inspired with ideas from research and searching other similar projects that requires analysis Where this part's results are: 15% Strongly agree 21% agree 38% neutral 17% disagree 9% Strongly disagree
The challenges that faced students in schematic design	It was given a weight of 60%	52% of students strongly agreed that they face challenges when they start with schematic design. The majority face the problem of trying to implement their ideas. They do not know how to transfer the ideas into architectural language and drawings. Therefore, they go with the easy flow of doing other things than that they were thinking of. Therefore, it is more like they come to this critical point and start from the beginning like nothing was done before Where this part's results are: 52% Strongly agree 40.5% agree 4% neutral 2% disagree 1.5% Strongly disagree

The majority showed that they face challenges and mostly this leads to the neglection of research and analysis phase to most of students in schematic design and starting from the beginning that results in making a gap between what is done in research and what is done in the delivered architectural project. Figure 8 shows the survey result in normal distribution curve showing mean and standard deviation.

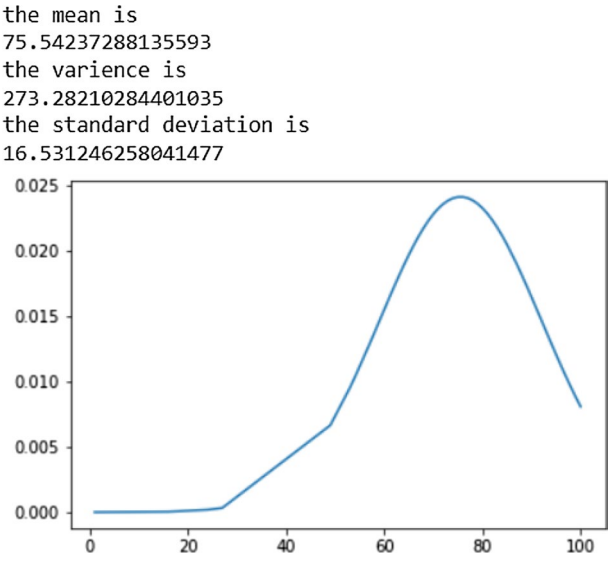

Fig. 8 Normal distribution for the survey result showing mean and standard deviation

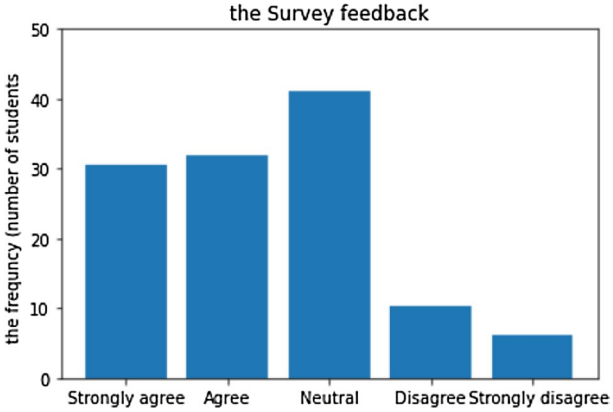

Fig. 9 Bar chart for the survey showing frequency

Figure 9 shows the results where: The range of grades of the survey is 100 to 20 and it will later be divided by 20 to make it range from 1 to 5 where:

- 1 corresponds to strongly disagree.
- 2 corresponds to disagree.
- 3 corresponds to neutral.
- 4 to agree.
- 5 to strongly agree.

Conclusions

From above, it was shown that there is a clear problem for students to relate what they do in research phase with what they are required to do in synthesis phase. From the results of fluency and elaboration thinking factors, it was noted that students have weakness point in

sketching and expressing ideas in architectural language. Which introduces the importance of using visualization design thinking tool as a method that would help students express their ideas and lead successful architectural project.

From the survey done after the experiment it was seen that students showed a clear and noticeable agreement in the fourth factor of the challenges that faces them in schematic design. Students showed that they do not know how to implement their ideas in clearway with the architectural language. Were the collected information they don't know how to benefit from it in design and so they don't know how to link the two phases together. They lake the skill of transformation the verbal information to architectural language.

Drawing and sketching is widely known to be the most common language of architects. it's what designers use to express their ideas and thoughts. As the theorist and architect, Marco Frascari said about drawing and how it could be a guidance to architects and designers to understand what is done and what they are about to do. He mentioned that the drawings done by architects are drawings of pure architectural thinking.

So, Visualization tool of design thinking is proposed to link analysis phase (research phase) done by students at the beginning of their architectural project to synthesis phase and have a successful schematic phase. It's proposed to use the visualization tool (visual thinking) at the end of the research phase.

Visualizing information makes it easy to understand and imagine. It can draw attention to any mistake or conflict especially when used in analysis and stating information. Using visualization is simple and easy in design especially in analysis phase at its end before beginning the synthesis phase. Student can change all verbal data collected and gathered in research into drawings and visuals with this method. So, the recommended steps are as follows:

1. Gathering data and information for the research.
2. Visualize all data as simple as possible.
3. Identify the design problem.
4. After knowing the main design problem breakdown, the problem into components.
5. Use different colors for each component of the problem.
6. For every component of the problem try to visualize it in the most possible and simple way to imagine it easily.
7. When thinking in ideas for solution sketch every idea and try to visualize it.
8. Have a quick sketch for the concept to test idea that solves solution.
9. Try using colors that was given to different components of the problem. In order to make sure that the solution proposed fulfills the needs of all sides of the design problem.

Future research

The findings in this study opens the possibility for future research in adopting and involving the design thinking tools more in the design process. Along with merging the visualization tool with other tools such as mind mapping. This requires more research on the availability of using design thinking tools with design-based learning in the architectural design education. That would result in achieving successful architectural projects.

Appendix

Survey

This survey is part of a research paper that aims to search for the reasons of unlinkage between research done by students in the beginning of design project for undergraduate students and the schematic design phase and use design thinking for linkage. This survey will help the researchers to develop architectural education for undergraduate students.

Your responses will be anonymous and confidential. The data collected from this survey will be used only for academic purposes and will not be shared with any third parties.

Your time and cooperation are highly appreciated. Thank you for your Participation.

Part 1: measuring student's benefit from research phase in the design process

1. How important do you consider the research phase in the design process?

    a. Not important
    b. Somewhat important
    c. Important
    d. Very important
    e. Extremely important

2. To what extent does research help you to understand the context and needs of your design project?

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much
    e. Completely

3. To what extent does research help you to generate design ideas?

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much
    e. Completely

4. To what extent does research help you to develop more innovative and effective design solutions?

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much
    e. Completely

5. How confident do you feel in conducting research for your design projects?

    a. Not at all confident
    b. Somewhat confident
    c. Moderately confident
    d. Very confident
    e. Completely confident

Part 2: measuring the impact of the research phase on the schematic design

(Schematic Design)

1. To what extent does research help you to generate initial design concepts for your schematic design? (Schematic Design)

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much
    e. Completely

2. To what extent does research help you to evaluate and refine your design ideas during the schematic design phase? (Schematic Design)

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much
    e. Completely

3. To what extent does research help you to incorporate user needs and preferences into your schematic design? (Schematic Design)

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much
    e. Completely

4. How much do you rely on research when making design decisions during the schematic design phase? (Schematic Design)

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much
    e. Completely

5. To what extent does research help you to create a more coherent and logical design solution?

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much
    e. Completely

Part 3: ideas generation and how students generate ideas for the architectural projects

1. How Often do you use sketching to generate ideas for your architectural projects?

    a. Never
    b. Rarely
    c. Occasionally
    d. Often
    e. Always

2. How Often do you use Brainstorming to generate ideas for your architectural projects?

    a. Never
    b. Rarely
    c. Occasionally
    d. Often
    e. Always

3. How often do you discuss your design ideas with others during the design process?

    a. Never
    b. Rarely
    c. Occasionally

4. Often

    e. Always

5. To what extent do you use sketching as a method for generating design ideas?

    a. Never
    b. Rarely
    c. Occasionally
    d. Often
    e. Always

6. How often do you depend on creativity and aesthetics when you evaluate your idea to determine which to pursue with?

    a. Never
    b. Rarely
    c. Occasionally

7. Often

    e. Always

8. To what extent do you use digital tools to generate your design ideas?

    a. Not at all
    b. Somewhat
    c. Moderately
    d. Very much

9. Completely

Part 4: knowing challenges that faced students in schematic design

1. How often does your generated ideas are the same produced in your schematic design?

    a. Never
    b. Rarely
    c. Occasionally
    d. Often
    e. Always

2. What are the biggest challenges you face when generating design ideas for your schematic design?

    a. Lack of inspiration
    b. Time constraints
    c. Limited access to resources
    d. Difficulty understanding user needs and preferences.
    e. Other (please specify)

3. What are the biggest challenges you face when refining and developing your design ideas during the schematic design phase?

    a. Difficulty incorporating user or instructor feedback.
    b. Limited access to resources
    c. Lack of clear design direction
    d. Technical difficulties with design software/tools
    e. Other (please specify)

4. What are the biggest challenges you face when incorporating sustainability into your design solutions?

    a. Limited knowledge of sustainable design principles
    b. Difficulty finding sustainable materials.
    c. High cost of sustainable materials
    d. Limited time to research and incorporate sustainable strategies.
    e. Other (please specify)

5. What are the biggest challenges you face when working in a team during the schematic design phase?

    a. Communication issues among team members
    b. Difficulty coordinating schedules.
    c. Conflicting design ideas among team members
    d. Difficulty delegating tasks.
    e. Other (please specify)

6. Where do you inspire your design ideas from?

    a. From research conducted at the beginning
    b. From site visit
    c. Searching internet
    d. Similar projects
    e. Other (please specify)

7. What are the biggest challenges you face when presenting your design solutions to others (e.g. professors, clients)?

    a. Difficulty articulating your design concept.
    b. Lack of confidence in your design solution
    c. Difficulty responding to questions and criticism.
    d. Time constraints during the presentation
    e. Other (please specify)

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Availability of data and materials All data, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no competing interests.

Ethical declaration The study was in a typical design studio that is in a design course given to undergraduates. All participants provided written informed consent for their acceptance to participate in this study.

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