Conceptual Design Framework and Taxonomy Assessment for Capstone Design

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Abstract

The Integrated Civil Engineering Capstone design were introduced to combined all the civil engineering discipline such as geotechnical, water and wastewater, environmental, project management, structure and road into one subject. The complex multiple constraints which were set by Engineering Accreditation Council (EAC) are compulsory for the Civil Engineering Bachelor degree. The designing of a complex solving with multiple conflicting constraints are developed in this course so that the students were trained to have achieved the level 5 and level 6 of bloom taxonomy level. The multiple criteria were tested for the students when the students were deciding the platform level for their project constructions. The multiple criteria were consisting of the time, cost, technical feasibility, societal, cultural, legal, and environmental and sustainability. These criteria were then evaluated based on the ranking matrix. The high, medium or low impacts of the criteria were assigned to each of the multiple criteria. Finally, the platform level was decided based on the criteria that have the lowest impact to the environment between the two layouts. The conceptual toolbox was used as guidelines for the student to propose the two layouts. This capstone design course is the key element to prepare the students to real engineering problems which requires the student to solve the complex solving with multiple conflicting constraints.

Keywords: Conceptual design framework, bloom taxonomy assessment, capstone design, sustainable development, conceptual toolbox

1. Introduction

The Integrated Civil Engineering subject has been introduced in Civil Engineering Degree course in UNITEN since 2007 as an elective subject. Engineering Accreditation Council (EAC) panel requires that we conduct a capstone design project as a compulsory course or subject and not as an elective. Hence, decision was made to make CESB 493 as Integrated Civil Engineering Design Projects as a compulsory subject/course effective semester 2 2008/2009. New total credit hours including capstone design subject as core subject has total credit hours of 127 credits. This subject is an authentic of real problems which is based on open ended problems with multiple constraint and solutions. The design framework must follow the demand criteria and provide solution to the multiple constrain. The conceptual design has six key parameters which must be considered in the design such as technical criteria, cost, time, sustainability and environmental, societal, legal and cultural issues and finally public health and safety issues. This paper is to discuss on the conceptual framework for capstone design which must comply with multiple constraint. The problem solving with multiple constraint and multiple solution is at the level 5 or level 6 of bloom taxonomy.

2. Development of Integrated Capstone Design subject in Civil Engineering Department

Capstone design subject has been introduced in civil engineering degree since 2007. This subject is integrating all the discipline in civil engineering design into capstone design subject. The discipline involve in civil engineering design such as planning and management, water reticulation design system, road and drainage, environmental issues, foundation of a structure, design building structure and last but not least the total cost of the project. Since the introduction of this subject, the students are well explained about the role of engineer when planning to construct a building. The students are more confident in their job as civil engineer because they already know the steps or the process from the planning until the claiming and hand over of the completed projects.

The types of the projects which are given to the student are such as designing a hospital, university, shopping complex and training center. There are three stages of capstone design process namely input, process and output. The input in the design comes from the local authority of the area, industrial consultancy projects and the authorities guidelines such as code of practice and literature review. The processes of capstone design are the problem analysis of the real projects. The students were taught to solve the real problems by getting the information about the projects by attending special lectures by industrial panel, the client consultant meeting which was done every week to discuss about the problem arise about the project and to get the feedback from the client about their needs. Then there are also processes such as schedule of task, monitoring of progress based on the project planning Gantt chart and evaluation by the industrial panel.

The output of the projects is where the students were assessed. The assessment of the student marks are based on the company profile and business plan, preliminary report which discuss about the conceptual design of the projects and the final report which give the detailed design of the projects. Other support documents such as condition of contracts, bill of quantities, specifications, drawings and design calculation need to be submitted together with final report as a requirement for tender document submissions. Figure 2.1 shows the flow chart of the process framework in the capstone design.

Previously, the students were only given one project which was shared with 5 groups. As the years goes on, different types of project has been given to the student. The assessment has become complex because each student has different projects which mean different problem constraints. Thus, a more systematic way of dealing with this differences are by introducing the conceptual toolbox. The conceptual design are developed based on the six key parameters which must be taken into consideration such as technical feasibility, cost, time, sustainability and environmental, societal, legal and culture and finally public health and safety.

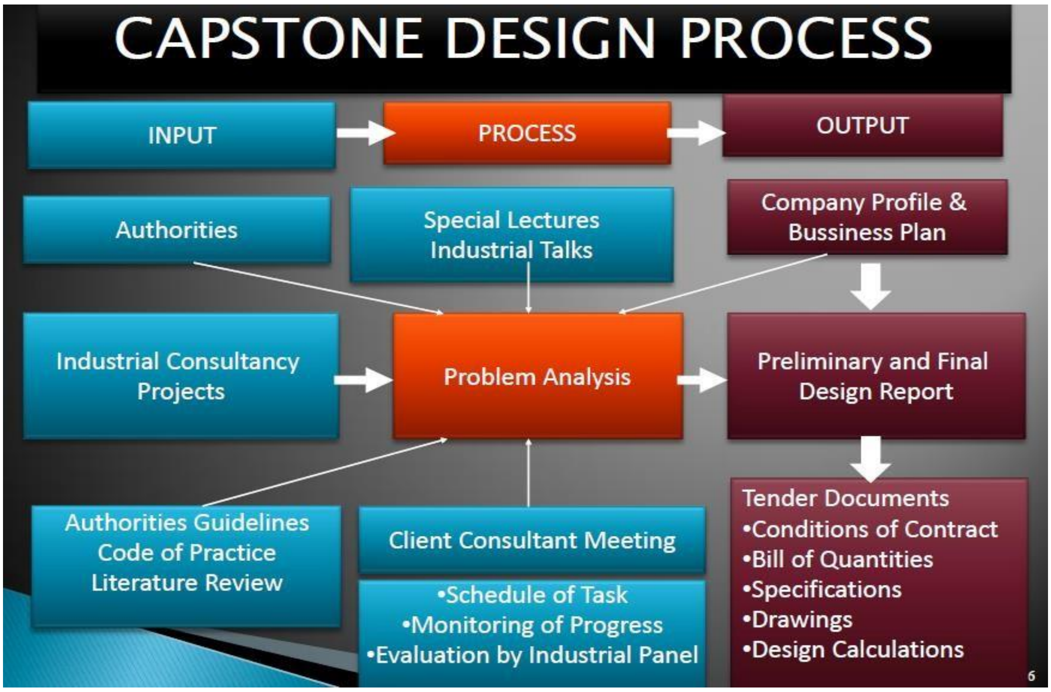

Figure 2.1: Process framework in Capstone Design Projects

2.1 Conceptual Design in the Design Process

The conceptual design in this course is done at the beginning of the project. In the conceptual design stage is where we define the platform of the structure, the types of material to be used for the structure, the types of frame system, and the planning of the projects. Conceptual design is probably the most inspiring part of engineers' task but at the same time the most demanding of all. The more experience the engineer, the more easily he or she can see the solution in his or her head and does not need to start from scratch. The contradiction becomes obvious as conceptual design has to be the most creative part of the design. On one hand, engineers do not need to invent the wheel every time they approach a problem. On the other hand, if they already predefine the answer in their mind, they are already neglecting most of the other alternatives which reduces the possibilities for new inventions and improvement of solutions. Thus, there must be some balance between conceptual design and predefine answer in the design process.

The general steps in design construction cycle are as follows: conceptual design, preliminary design, detailed design, tendering and award, site possession, construction, and handover and defect liability period. In the design construction process, if time has been spent more on conceptual design, then, the total time for completing the entire process would be reduced. The defect and liability time and money for projects would be reduced if the conceptual design has been done thoroughly. Engineering problems are under defined; there are many solutions, good bad and indifferent. The art is to arrive at a good solution. This is a creative activity involving imagination, intuition and deliberate choice.

The relationship of conceptual design in the design process must start from the theory and fundamentals of engineering knowledge. Conceptual knowledge is defined by [1] as a connected web of knowledge; a cognitive network in which relations between nodes are as important as the discrete pieces of information constituting these nodes. The knowledge of conceptual engineering are applied in the structure design, foundation design, water and drainage flow, cut and fill of the earthwork and etc. According to [2], this knowledge is needed to identify problems and generate new strategies or adapt known strategies to solve original problems. This knowledge must considering the six key parameters in the conceptual design. The selection of platform level for the structure would have affect the time, cost, technical feasibility, sustainability, and public health and safety. If the six parameters have been sufficient, the preliminary design could be started. In the preliminary design, the design must follow Universal Building by Law (UBBL), authority guideline, BS standard codes and Euro codes. The preliminary design will decide the types of frame system, the total number of floor, the location of the drainage system, the total volume of cut and fill, and environmental planning and the safety gradient of cut slope. The decision of the preliminary design must also take into consideration of the existing road to connect to the new platform level. The gradient between these two platforms cannot be more than 8% or 0.08 in gradient based on the authority guidelines.

The detail design process will proceed based on the finalized conceptual design. The spreadsheet, design software and CAD software will make the detailed design process easier and faster. For structure design, ESTEEM software or STAADPRO will be used in the detailed design. The final stage in the conceptual design process is evaluation and justification. The optimal solutions for the detailed design are tested based on the selection of material of the structure to get the most optimal design with minimal cost. The software would help in calculating the optimal design for the capstone design projects.

Based on [3], the students need to be exposed to the conceptual knowledge before entering the workforce. Thus, when developing the conceptual design, the concept map was introduced. Concept maps visually represent student's knowledge structures and meanings in a particular knowledge domain [4]. In this capstone course, the conceptual knowledge is presented using conceptual design toolbox as to fulfill the infrastructure demand.

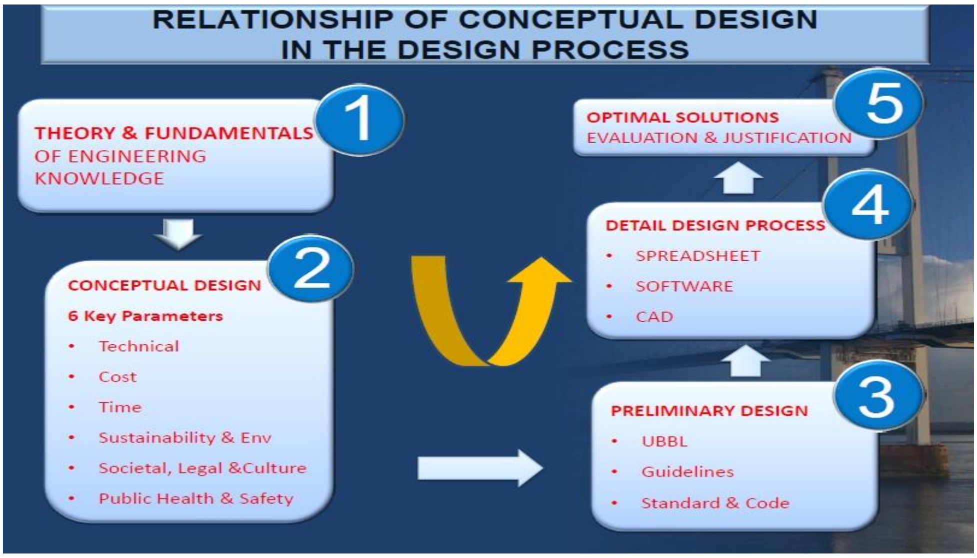

Figure 2.2: Conceptual Design in the Design Process

The conceptual designs were introduced to the undergraduate students in order to prepare them for their future working environment. For example, NASA has integrated their projects with undergraduate students in University of Alabama, USA. Based on [5], the integration of NASA faculty projects with an undergraduate engineering capstone design class would enable the students to enter the workforce familiar with what is required to design, develop, operate and maintain a complex system. The students will able to enter the workforce from being able to define various acronyms to understanding the tools and processes of engineering design, the learning curve of the students will not be steep upon entering the professional workforce.

Apart from that, the growing interest in sustainable development has made a number of universities engaged in sustainable development in educating the future leaders, decision makers, scientists and engineers on how their decisions can help societies become more sustainable [6]. The same goes to this capstone design course, the student need to take the sustainability concept when they design the buildings and when deciding the platform level. The development of sustainability-educated and empowered students in the academic curriculla will ensure that the societies will change into sustainable societies [7]. The sustainable societies means the challenge that the society will face such as the use of natural resources the way we generate and use energy, the role that stakeholders will be playing on the implementation of newer technologies, and in collaborating with other universities, companies, governments and civil society.

2.2 Demand Criteria with Multiple Conflicting Constraints

In 2010, Engineering Accreditation Council (EAC) would require the student to design a complex problems solving with multiple conflicting constraints. The complex problem solving are the level 5 and level 6 in the blooms taxonomy. In the capstone design subjects engineering, the student are assigned with multiple constrain which the student need to take into consideration when deciding for platform level of the structure. The multiple constraints are to suit all the demand criteria which are the consideration in the total cost, technical feasibility, time of construction, societal, cultural and legal demand, and finally the sustainability and environmental demand. Figure 2.3 shows the multiple constraints which were higher bloom with level 5 and level 6. Level 5 is synthesis level where the students were tested to use old concepts to create new ideas, design and invention, composing, imagining, inferring, modifying, predicting and combining. Furthermore, evaluation is level 6 where the students were assessed on the comparisons of ideas, evaluating outcomes and rating. These levels of blooms were assessed by on how the student deciding by evaluating the platform level for a given capstone projects.

The students are required to propose two platform levels for the projects. The platform level objective is to have a balance cut and fill. Other than having balances cut and fill, the students are required to test the location of the structure whether it was technically feasible. The students need to propose the location of the building. The orientation of the building is also important whether it face the sunlight or daylight. The main orientation is likely to be East-West along the main slope contours with the east/west facing elevations smaller in size than the north/south ones. The south and east/west elevations can also be provided with effective sun breakers as provided on buildings on the rest of the site. Good daylight and sunlight, such as orientation of the building will play an essential part in the psychological well-being of occupants and have an effect on productivity in the workplace. Moreover, the platform level would also have technical constraints.

Figure 2.4 shows the multiple technical with conflicting constraints arising when the students have chosen their platform layout. The technical conflicting would require the student to evaluate and justify their platform level and layout whether it have fits all the requirements for technical constraints. The technical constraint such as parametric constraint, limiting values, specific design output requirements, code requirements, authority design criteria, conditional requirements, and finally site constraint.

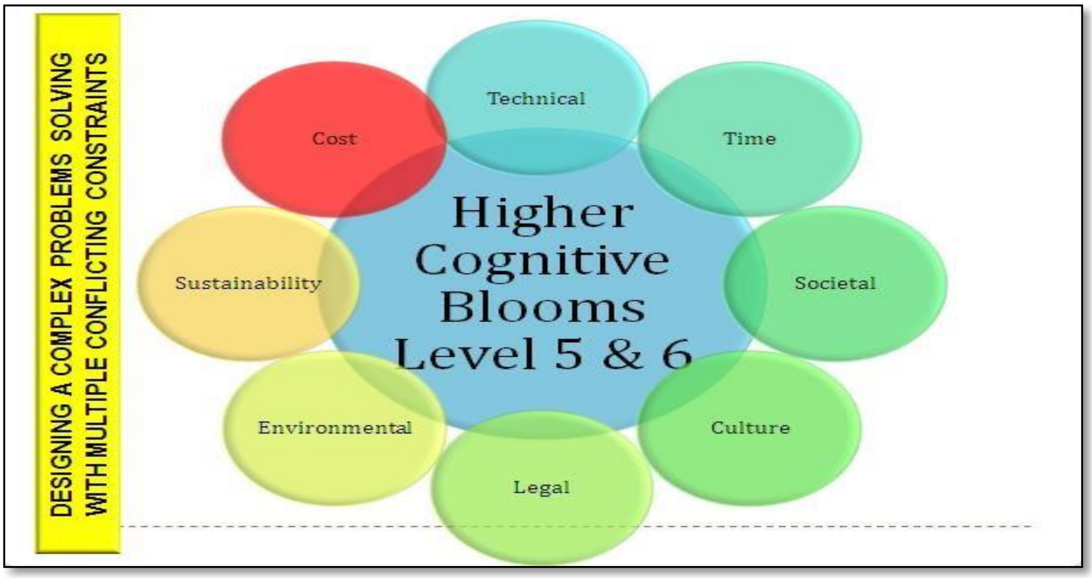

Figure 2.3: Multiple constraints in Capstone design with higher blooms of level 5 and level 6.

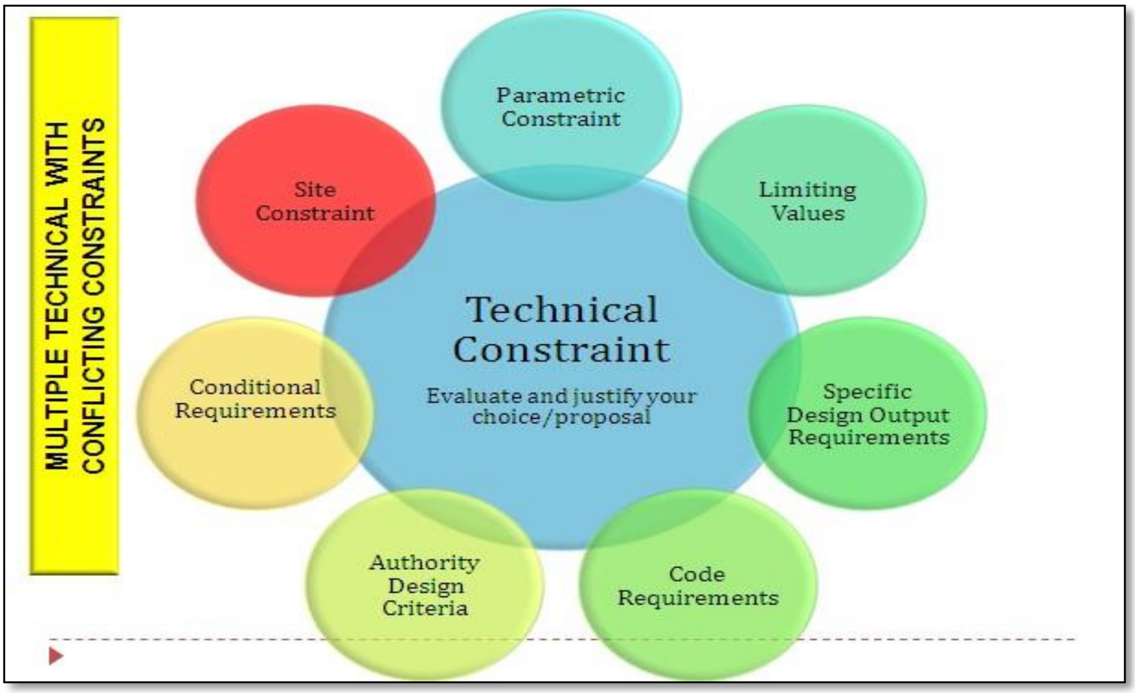

Figure 2.4: Technical constraint which the students need to evaluate the proposed platform level

Site constraints in deciding the platform layout are due to the location of the buildings. The location of the buildings may have some topography constraint whereby, maybe it was located at the hilly area or near the swamp area and up the stream. The students need to decide the exact location in between the hilly and the swamp area. Figure 2.5 shows the topography of the Bukit Jalil area which consist of hilly and swamp area for the proposed projects for capstone design.

Moreover, there were also parametric constraints where the road requirement by JKR Arahan Teknik has some speed limit for the road design. For example, the speed limit for urban area is 40 km/hr which the road width should be 3.50 meter for two-lane way and 1.50 for shoulder width. Thus, the students need to follow this parametric constraint. Moreover, in cut and fill calculations for determining the platform level, not only the time and cost constraint need to be comply, but also the economical design. This is the parametric constraint where the cut and fill must be balanced. The location of import and export the soil must be taken into considerations because it would be costly to import the soil if the area is in the need of more fill materials. Thus, the economic value is more preferable compared to parametric value in cut and fills calculations.

In addition to that, the conditional requirement in technical constraint would refer to the requirements by client and architect. For example, the architect may require the size of column about 450 mm. But the codes was not allowing the column size to be lower than 450 mm due to the slenderness ratio and buckling effect. Thus, the students need to think outside of the box by innovating the column into composite materials which by replacing the concrete structure with steel structure. Thus, the structure can have column size of less than 450 mm with composite materials without denying the BS CODES and EURCODES requirements.

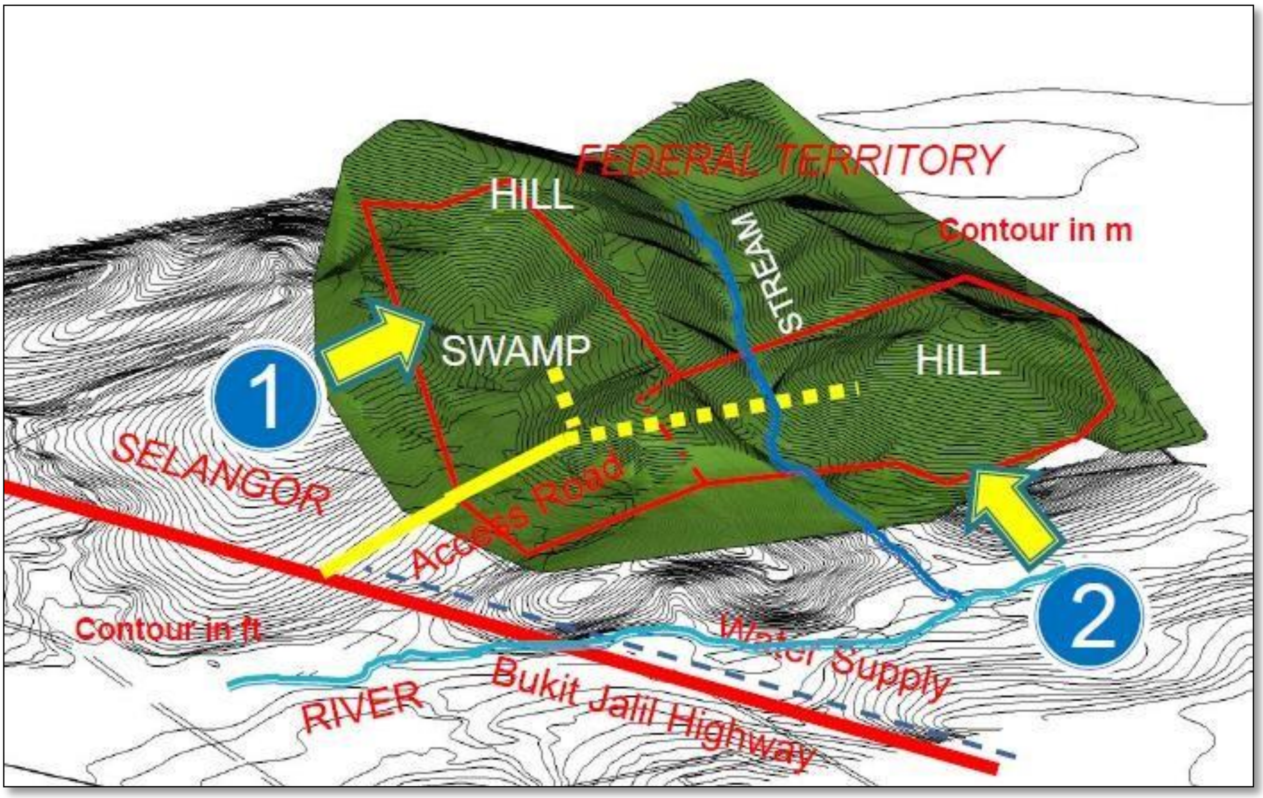

Figure 2.5: Topography of Bukit Jalil Area where the students need to propose the platform level for Capstone Design projects

Furthermore, the technical constraint would also have the limiting values. For example, in the assessment the types of material in the site investigations, there are some limiting value to the types of unsuitable materials for construction. The soil with high organic material content and the liquid limit of more than 55 percent are not suitable for the construction of building. This is the limiting value that must be considered in technical constraints.

Other technical constraints such as code requirements and authority design criteria must be followed. The code requirements are based on the fundamental concept of the design while the authority guidelines are based on the requirement by the authority. Authority have some requirement so that the local authority for certain area have some standard or similarity, thus in order for the projects to get approval, the local authority requirement are the main key issues.

3. Conceptual Design Framework of Capstone Design

In the conceptual design, there are five steps approach which was introduced by [8]. The five steps are: need definition, design requirements, key parameter identification, configuration and evaluation. The first step in conceptual design is need definition. The project need some definition in terms of location of the building layout and its platform levels, cost estimate, what infrastructure services needed and the structural systems, materials with its construction methodology. When the criterion of the building has been defined, the design requirements for the building are review based on its technical aspects such as codes, legal issues, site constraints, authorities' requirement and etc. If the needs are correctly identified then the risk of changing the whole design later during the design phase has been reduced or eliminated. One procedure to identify the real needs of the project is to list all questions and issues systematically.

In the design requirements stage, it gives a summary of the minimum needed functions and constraints. Design requirements do not mean checking the performance and properties of the product, since this can lead towards predefined solutions, which again can be a hurdle for innovative design. Since design requirements guide the design process, the quality of the product is directly influenced by them.

The step three is key parameters identification. This step is the simplicity of the task and transformation of it into a more abstract problem. By identifying the most important points to the client, generation of ideas and solutions are made. These solutions should try to satisfy the key parameters as much as possible. Simplicity is done by depriving the less important factors or removing those factors, which are not important in the beginning or during the conceptual design phase but can be relevant in the later stages. Secondly, trying to solve the most critical problems first is the way to be able to continue developing the concept further.

The step four is configuration. Configuration is more detailed information about the proposed solutions with sketches, preliminary calculations and explanations is worked out. For the evaluation of the physical configuration, it is important to define some parameters like dimensions and material choice. Since this is a repeated process, several options will arise. Moreover, opposite to parameter identification, configuration is quite a divergent process. Figure 3.1 shows the five step methodology proposed by Niemeyer (2003) to be implemented in Capstone Design Projects.

The final step is evaluation. In this evaluation step, the proposed solutions in step 4 are evaluated and ranked according to different parameters. One of the most critical steps is the key parameter identification. The solutions that remain as promising must be further evaluated and compared. In order to do that, the engineer must know which parameters and qualities of a specific buildings and its infrastructure are of greater importance for the client.

The students were tested by assigning the conceptual toolbox to the students in Capstone Design projects. The students need to propose 2 layouts for infrastructure demand. In order for the student to propose the layout, the students need to consider the 7 criteria such as geotechnical criteria, project management, economical, environmental, safety and public health, highway and drainage, and water supply.

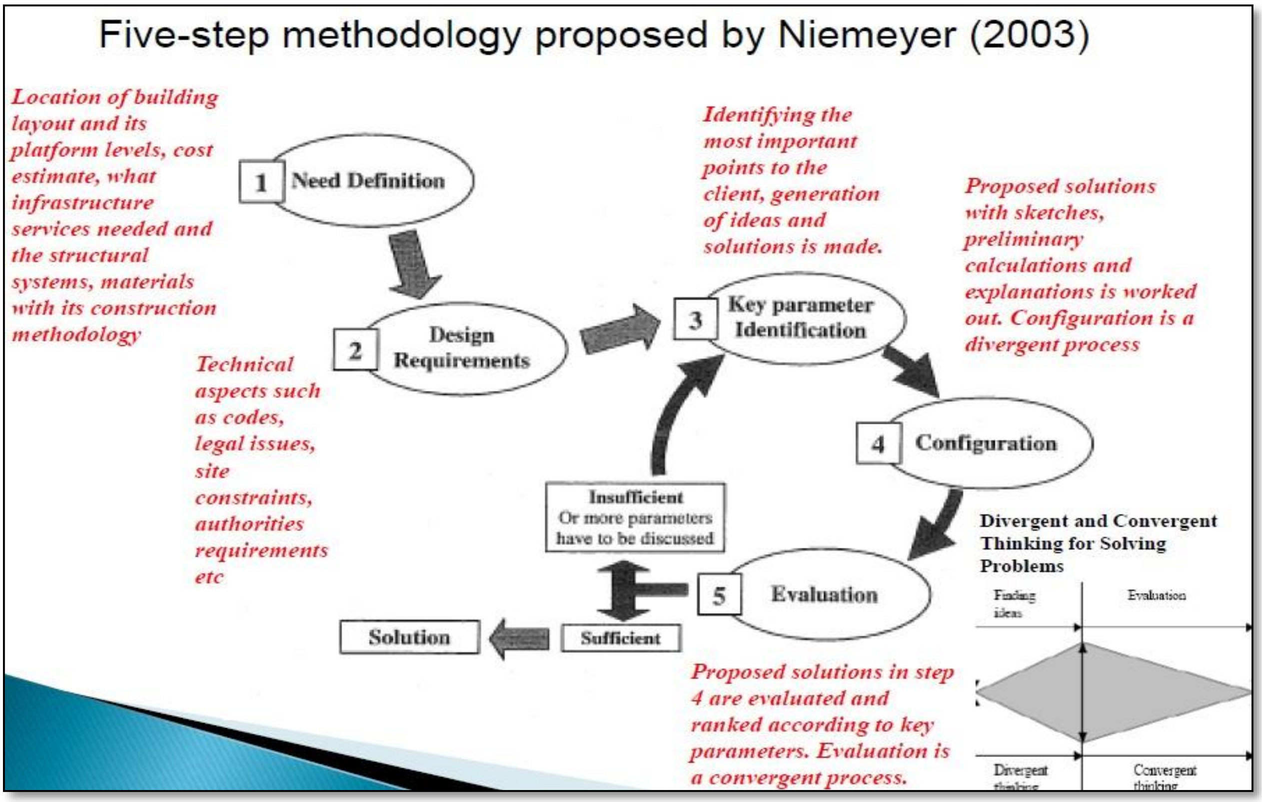

Figure 3.1: Five step methodology proposed by Niemeyer (2003) to be implemented in Capstone Design

The propose layout must taken into consideration of the total cut and total volume of the earthwork in order to decide the platform level. In terms of economic criteria, the cost efficiency and time efficiency were compared between the two layouts. For example, in propose layout 1, the location is quite near to the access road, thus it is cost efficient for constructions and time efficient for construction. In terms of environmental criteria, the students need to think about the production of waste during the construction, the sustainability of the material, efficient use of resources and materials, and environmental management planning during the construction.

When proposing for the platform level, the students need to also analyze the available pressure head, SYABAS guidelines (authority guideline), MWA guideline, elevated water tank, tapping point and water demand. All the analyses are for water supply purpose to the constructed building. If all the criteria have been fulfilled, then the best layout is selected. During the constructions, the safety and health issue of the workers are addressed in the capstone course. The site safety such as safety net, scuff folding, buffer zone and other safety features of the workers so that the construction have zero accident during constructions. The student need to propose the safety measures taken for the propose layout. Other than that, the health control, workers accommodation and site sanitation. The details of the conceptual toolbox on infrastructure demand are shown in Figure 3.2.

The project manager plays a major role in the planning of the capstone project. The project manager has to plan based on the timeline either by Gantt chart or Microsoft project planning. The project needs to be completed on time. The project manager is also the person that will be in charge of determining the preliminary costing, bill of quantities, specifications and condition of contracts. The project manager is the leader of the group which will lead the team members to follow the project conceptual development. The completion of the projects depends upon the project manager to manage the team members and complete the task within the given time frame.

The second important person is the geotechnical engineer. The geotechnical engineer will determine the suitability of the ground for construction of the building. The platform level must follow the authorities' guideline and have a balance cut and fill. The geotechnical engineer would also design the slope beside the building and the foundations of the buildings. The stability of the slopes was calculated based on the factor of safety. The groundwater level was also check by the geotechnical engineer based on the site investigation reports. The types of foundation based on the loadings of the structure are design in this course. It can be summarized that the project manager, geotechnical engineer, highway engineer, environmental engineer and water engineer are equally important in proposing the conceptual toolbox on infrastructure demands.

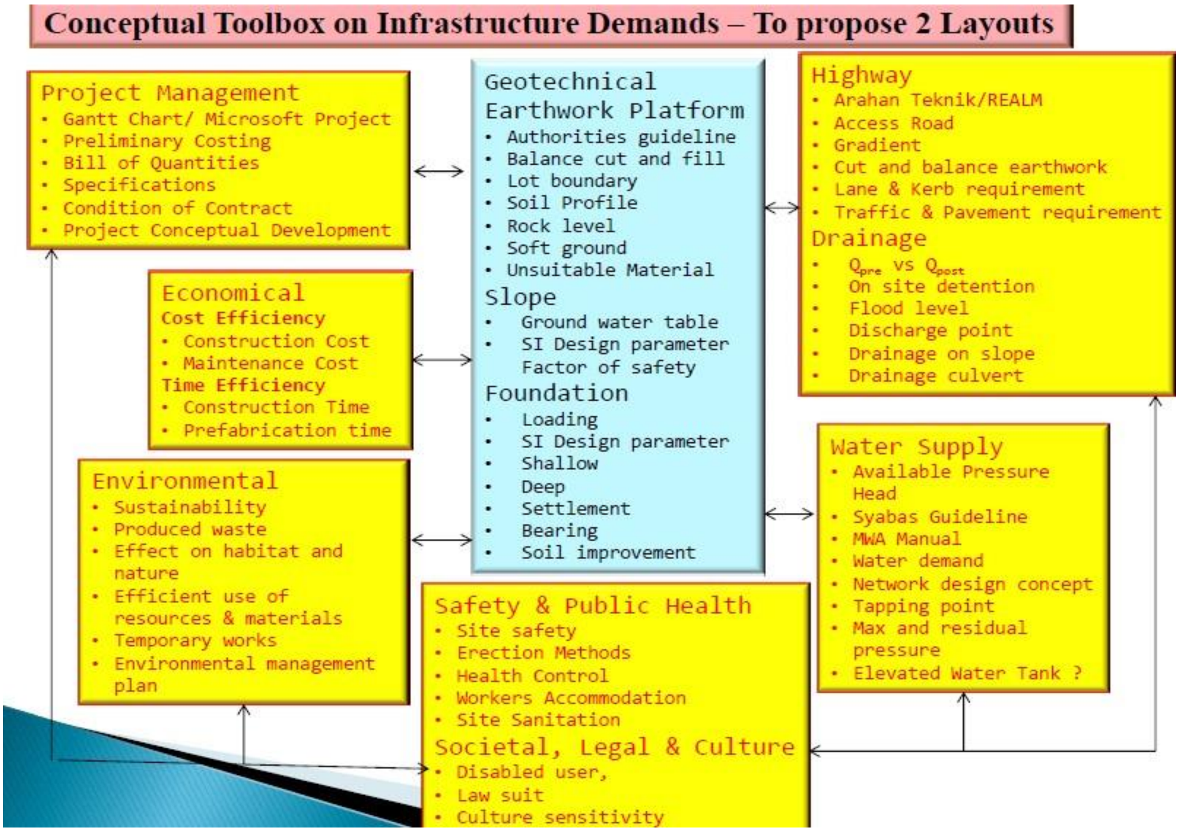

Figure 3.2: Conceptual Toolbox on Infrastructure Demands

4. Discussion

The capstone design course is designed to integrate the five areas in civil engineering course. The conceptual design need to be proposed by the students before the design process. The conceptual must be clearly defined at the beginning of the projects. The students need to think on the sustainability of the buildings that they were designing, the social impacts of the building to the developed area, and the reuse of the waste material. The conceptual design must also consider to minimize the waste accumulations. The minimizations of the waste are applying the sustainable concept to protect the environmental from pollution. The student need to think of the sustainability of the buildings, road and drainage by suggesting the invention for the green technology such as using the green materials for structure, recycling the tire rubber for road pavement and the grass swale for drainage system.

The students need also to come out with the conceptual toolbox for the infrastructure demand. The students have to propose 2 layouts and think about the ranking matrix of each layout. The comparisons in terms of the platform level between these 2 layouts are done using ranking matrix by assigning the scale from low to high scale for time, legal and societal, technical feasibility, and cost. This ranking matrix is the high bloom of level

6 because the students need to consider multiple criteria in the decision making. Thus, this capstone design course has trained the student to use their thinking skills up to level 6 of bloom taxonomy.

5. Conclusion

In conclusion, the conceptual design framework and taxonomy assessment for capstone design are developed for this course. The designing of a complex solving with multiple conflicting constraints are developed in this course so that the students were trained to have achieved the level 5 and level 6 of bloom taxonomy level. The multiple criteria were tested for the students when the students were deciding the platform level for their project constructions. The multiple criteria were consisting of the time, cost, technical feasibility, societal, cultural, legal, environmental and sustainability. These criteria were then evaluated based on the ranking matrix. The high, medium or low impacts of the criteria were assigned to each of the multiple criteria. Finally, the platform level was decided based on the criteria that have the lowest impact to the environment between the two layouts. The conceptual toolbox was used as guidelines for the student to propose the two layouts. In the conceptual toolbox on infrastructure demand, the geotechnical design, project management, environmental, societal, legal and health, water supply and highway must be addresses in their design.

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