An Environment Based Design (EBD) Approach to Designing a Framework for Staffing Conceptual Design Projects

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Abstract

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Amirali Ommi

Conceptual design projects are commonly complex projects that need more than one individual designer to work on them for project accomplishment. This group of people gathered together toward a similar objective of accomplishing a project is called a design team. The design team is a crucial success factor in conceptual design projects and designing the design team remains an inevitable part of the design problem for any project manager.

In this thesis, we approach the team design problem by employing a design methodology called Environment Based Design (EBD). Along with demonstrating the application of EBD in this design problem we propose a framework which can support the project manager in human resources management processes in a design project while complying with PMBOK as a widely-practiced project management method. Finally, we conduct a case study to validate the effectiveness of the proposed framework.

This thesis provides two models which can support the designing of a team during the project execution. The first model introduces an approach for designing and evaluating projects in the project-based learning context regarding the learning objectives. The other model is a descriptive model which describes the design phenomena in a design team based on a theoretical model of creativity and organizational capability. Using these two proposed models, the project manager can maintain the design team performance by training the team and resolving raised conflicts among the team. These models are provided within an integrated and systematic staffing framework which enables the project manager to staff conceptual design project teams by appropriate designers effectively throughout the conceptual design project.

Acknowledgement

I have been studying engineering for more than ten years through which you learn much about different models and methods to solve typical problems. During the past three years, I was honoured to research under the supervision of Dr. Yong Zeng who has taught me something extra about how to think and how to be creative while following specific steps. I believe I can take this approach to almost any problem in my life, so it is not a wonder that I want to thank him first and foremost.

I want to thank my parents and my dear sister (whom I am witnessing her accomplishments one after the other from far away) for their unlimited and devoted love and encouragement that has always been a great resource making me brave and capable of endeavouring for more success. There is no doubt that they are my most precious asset in the world.

As an international student, I have faced many challenges other than studying throughout my master's program in beautiful Montreal which I could not withstand them without my friends heartening me. I am obliged to thank many of them for being beside me through the hard days and on top of them Afshin Bayatpour and Saeid Vosoughi and all lovely humans whom I had the chance to have in Montreal.

I was fortunate to work with my talented colleagues in the "Design Lab" at Concordia University whom I learned a lot from, and I have used their insights and comments inevitably in my works. I must mention their support during my internship in China as well especially Shi Yuyang who was there for me. I want to thank Xiaoying Wang for her help in conducting the case study that supports this thesis. I like to thank everyone in the "Design Lab."

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Chapter 1

Introduction

1.1. Background and Motivation

Design is an activity in which the designer change the environment to a desired one by creating a new artefact [1]. In other words, design is an activity which aims to provide a solution that meets specific requirements. Staffing is crucial to project accomplishments and in our research, we are approaching the staffing problem as a design problem. Using design methodologies are effective in coping with design problems and as we are tackling the staffing problem as a design problem, we are using a design methodology named Environment Based Design (EBD) Methodology.

Design problems are commonly complex problems which need a design team for their accomplishments rather than individual designers. “Concordia Design Lab” has provided many models for studying design activities for an individual and recently it is ready to take these models to the next level to propose and validate models which can be used for studying design activities and processes among design teams.

In studying design in the context of Environment Based Design (EBD), one crucial element is the designer itself which in our study is a team of designers called a design team. This research approaches the design team as a product of the staffing design problem which is concerned about building and maintaining an effective team for conceptual design problems — a problem which may be solved effectively using a design methodology as Environment Based Design (EBD).

1.2. Objective

We approach staffing as a design problem, so we will benefit from employing a design methodology. Employing the EBD methodology, we attempt to design a framework which can be used to support the human resources processes management and staffing processes for a conceptual design project. Meanwhile, there is a range of practices for project management with the PMBOK on top of the list which provides an

appropriate framework for managing a project from different perspectives. We are interested in developing a framework which is compatible with these practices.

Considering that a project has a certain workload, the requirements of the staffing design problem in projects is to assign right work units to the right people or in simple words forming and maintaining an effective project team. Our research proposes an integrated framework which provides processes to support the staffing in a design project regarding indicated concerns. Thus, it can support the staffing processes throughout a design project effectively, by accommodating mentioned requirements in the staffing framework as the solution. As a case study, we have applied this proposed staffing framework in a design session to validate its effectiveness.

As mentioned in the background and motivation, commonly design projects are complex tasks which are accomplished by a design team; this complexity brings up another concern. Once the team is formed, during the execution of the project it's important to make sure that the team is developed and managed effectively. To do this properly in design projects, we need to have a good understanding of the design phenomena and how it is done within a team. Regarding this concern, we are also providing a descriptive model to describe the design phenomena in a team setting and we observe its performance in a case study.

1.3. Contributions

The thesis contains the following contributions:

1- Developing a staffing framework utilizing Environment Based Design (EBD) approach. This framework supports the human resources management processes in a design project in compliance with the Project Management Body of Knowledge (PMBOK). Table 1 demonstrates framework modules analogous to PMBOK processes for human resource management. While PMBOK provides the processes framework, it does not provide specific tools for running those processes, the framework that we propose will provide tools for supporting those processes, and since we are approaching this as a design problem, we are going to use the EBD design methodology for solving it.

PMBOK Process	**Corresponding Framework Module**
Developing the human resources management plan	Workload analysis
Acquiring the project team	Team acquisition
Develop team	Team development
Manage team	Team management

Table 1 - EBD based staffing framework supporting PMBOK human resources management processes

2- Using a theoretical model of design creativity and the organizational capability model to describe the design process in a team which is coping with a design project.
3- We have Conducted a case study of applying the proposed framework for accomplishing a flying house conceptual design project in a team. This case study supports the validity of the proposed framework. The results from the design session can be used for further analysis.

1.4. Research Methodology

In this research, we use theories along with a design methodology to develop a staffing framework which can support a conceptual design project regarding human resources management processes effectively. Afterwards, we implement this framework in a conceptual design project to demonstrate its effectiveness, so the framework can be justified upon project accomplishment.

1.5. Thesis Organization

The rest of this thesis is organized as follows:

Chapter 2 presents theoretical foundations based on which the proposed framework is designed. In this chapter, the Environment Based Design (EBD) methodology is introduced as well as a theoretical model of creativity.

Chapter 3 provides a literature review on team design problem and different approaches for studying it. By the end of this chapter, we position our research among the introduced literature.

Chapter 4 demonstrates the application of EBD to design the staffing framework and presents the followed steps. It also discusses project-based learning for team development and mental models sharedness for managing design teams. At the end of this chapter, the solution and its details are presented.

Chapter 5 presents a case study of a design team which copes with a conceptual design project for designing a house that can fly. In this case study, the proposed framework is employed to manage the project. The final design solution is validated to investigate the validity of the proposed framework for its targeted application.

Chapter 6 presents the conclusion which summarizes the findings in this thesis and the approach for extending this research and future works.

Chapter 2

Theoretical Foundations

In this chapter, we introduce the theoretical foundation for our research. This introduction facilitates the presentation of research results in this thesis. We have used Environment Based Design (EBD) [1] as a design methodology to approach solving our research problem as a design problem, so the EBD methodology is presented here along with its underlying steps and associated concepts. In this thesis, we are presenting the results from studying designers while they cope with a conceptual design problem and we have used a theoretical model for design creativity [2] to describe the design phenomena; this model is also presented in this chapter.

2.1. Environment Based Design (EBD)

Environment Based Design (EBD) is a design methodology which has been developed for solving ill-structured and poorly defined design problems by achieving creative solutions [1]. In 1991, Zeng used "Axiomatic Theory of Design Modeling" [3] to introduce EBD based on the recursive logic of design.

EBD introduces some specific steps to support the design process for designers. Sine EBD introduction to the literature of design research, researchers have put efforts into developing tools to support EBD steps as well as applying EBD methodology and associated tools to solve real-world problems. These efforts have led to many available tools as well as many successful applications.

From the EBD perspective, the design is an activity that aims to change an existing environment to the desired one by creating a new artifact, namely, product into the existing environment. From EBD perspective environment is where a design originates with, serves its purposes and creates changes. Theoretically, the environment is everything except the product itself.

As mentioned above, EBD provides specific steps to be followed for a creative solution to a design problem. Main steps for this process are environment analysis, conflict identification, and solution generation. Figure 1 - EBD design process depicts the design process which is introduced by EBD. The mathematical foundation behind this methodology can be found in [4].

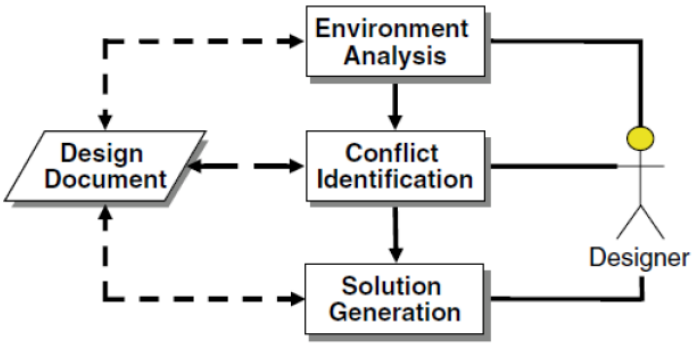


Figure 1 - EBD design process [1]

If we observe the design methodology as a process, the input for this process would be the design problem statement, and the output will be the design solution which can effectively and efficiently solve the problem and satisfy requirements which exist in the problem statement. We cannot assume applying a standard procedure on a variety of problems, namely design problem unless we can standardize the input which is the design problem. Hence, for applying EBD on a design problem one must present the statement of the design problem in a certain way, so applying EBD will become possible. In EBD, the meaning structure of a design problem is represented by Recursive Object Model (ROM) [5]. In this order, we will present the ROM concepts and ROM diagram before proceeding with EBD steps' introduction.

2.1.1. Recursive Object Modeling (ROM)

Earlier in this chapter, we mentioned the axiomatic theory of design as the basis for EBD methodology. The axiomatic theory of design modelling has two principal axioms [3] which are defined as:

1. "Everything in the universe is an object."

2. “There are relations between objects.”

Recursive object model (ROM) is a graphical tool which is presented for modelling linguistic information throughout a design process [5]. According to the first axiom introduced above, everything in the universe is an object, and a graphical symbol is provided by ROM to model this object which is depicted in Figure 2**.** The other axiom in the axiomatic theory of design indicates that objects have relationships with each other and accordingly, ROM provides another tool for representing different relationships between objects in the universe. Abovementioned symbols are presented in Figure 2 with their associated descriptions. These relationships are proven to be sufficient for technical English writings [5].

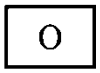
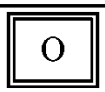
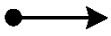
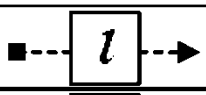
Type		Graphic Representation	Definition
Object	Object		Everything in the universe is an object.
	Compound Object		It is an object that includes at least two other objects in it.
Relations	Constraint		It is a descriptive, limiting, or particularizing relation of one object to another.
	Connection		It is to connect two objects that do not constrain each other.
	Predicate		It describes an act of an object on another or that describes the states of an object.

Figure 2 - Elements of Recursive Object Modeling (ROM) [6]

Now that we have introduced ROM, we can formulate the design problem and apply EBD methodology to the design problem. Following, we will explain each step of the EBD design process.

2.1.2. Environment Analysis

We have introduced the ROM which can make the linguistic information during design more useful by representing it in a standardized manner which can be analyzed as well. This capability can facilitate coping with a design problem for a designer regarding that the design problem is not presented in a formal structure often but can be formally presented by ROM that can be further analyzed [7]. The objective of the environment analysis step is to identify the environment in which

the product is to work. This step is mainly concerned with eliciting the right product requirements in the environment by finding out the real intent of the design problem. According to the recursive logic of design, one cannot well define a design problem without a design solution in mind and on the other hand, one cannot create a complete design solution without a well-defined design problem [1].

For well-defining the design problem, the first step is to represent it in a formal structure which is ROM, and in the next step, we should look for the right information about underlying concepts in the environment and their relationships with each other. Obtaining the right information about the design problem is a critical step and is only possible by asking the right questions. Therefore, Zeng and Wang propose a method for asking proper questions in a generic inquiry process [7] followed by answering them according to a proposed guideline. They show that this method is effective for eliciting product requirements. This process is presented in Figure 3.

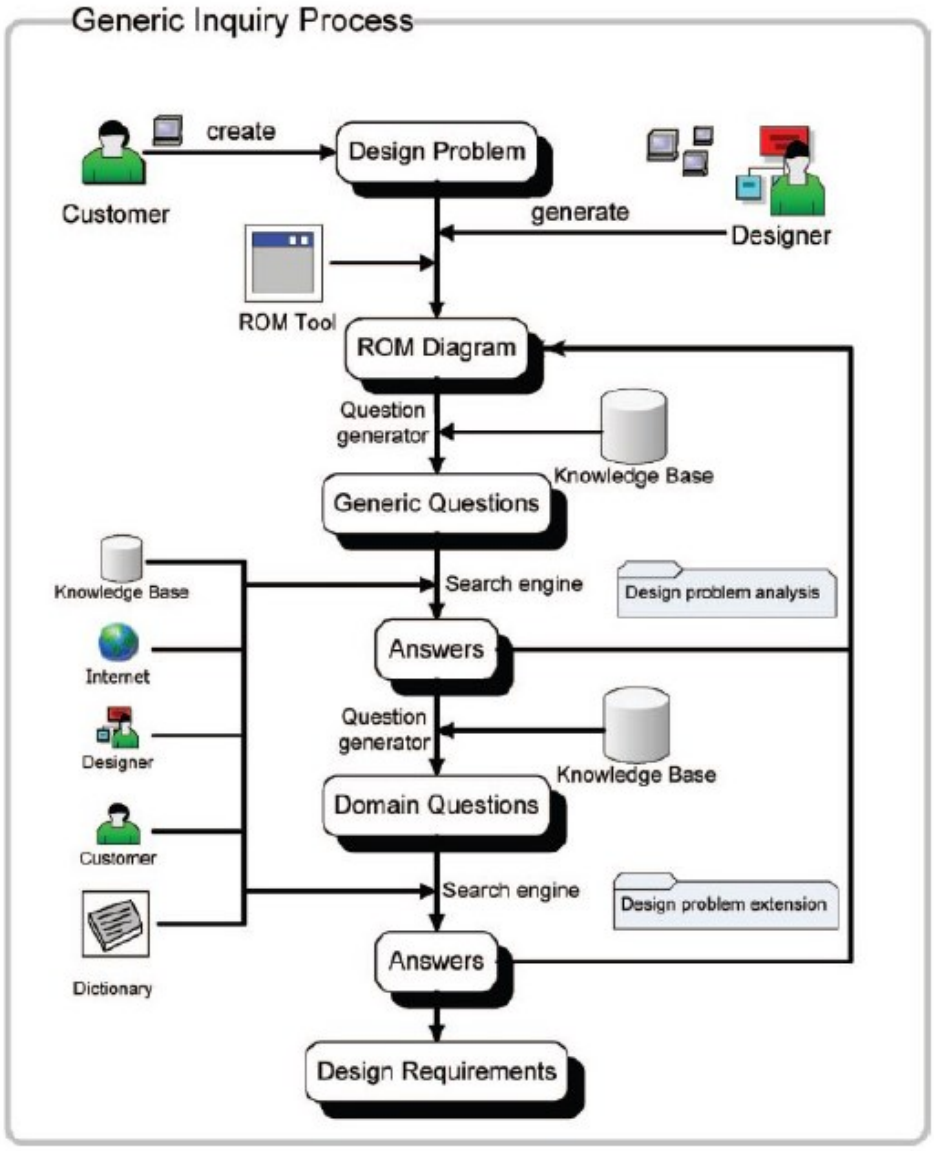


Figure 3 - Generic inquiry process for eliciting product requirements [7]

This research followed by [6] proposes rules for generating the right questions and templates for answering them according to their specific situations.

Good questions are right types of questions which are asked about right objects and in the right order. Rules provided in Table 2**Error! Reference source not found.** shows how to find the right order of question asking as well as the right object to ask the question about. For asking the right type of questions, a template is provided which is presented in Table 3.

Table 2 - Rules for finding the right object and the right order [6]

Rule 1	Before an object can be further defined, the object constraining them should be refined
Rule 2	An object with the most undefined constraints should be considered first
Rule 3	If an object has them most number of constraints and/ or predicates on other objects, then it should be considered first

Table 3 - Template for asking the right type of question [6]

#	Conditions	Question Template
T1	For a concrete, proper, or abstract noun object N without any constraint	What/ Who is N?
T2	For a concrete, proper, or abstract noun N with an adjective constraint A	What is A N?
T3	For n noun Object A constraining a noun object N	What is A? What is/ are A N
T4	For a verb V with its subject N1 and object N2	What do you mean by V in the statement "N1 V N2"? How do/ does N1 V N2? Why do/ does N1 V N2 When do/ does N1 V N2? Where do/ does N1 V N2?
T5	For a verb object V constrained by an adverb A with its subject N1 and object N2	What do you mean by V A? Why do/ dopes N1 V A N2? When do/does N1 V A N2? Where do/ does N1 V A N2?
T6	For a verb V with an object N, but missing its subject	What/ Who V N?

The objective of environment analysis step is to identify the product for design, the environment components and the interactions between the product and the environment as well as the interactions between the environment components itself. While different perspectives provide different organizations of environment components, Chen and Zeng provide a classification of

product requirements [8]. This classification leads to a generalized classification for the product environment which consists of natural, built and human environments. This classification is presented in Figure 4 and provides a representation of the spatial dimension of the product environment.

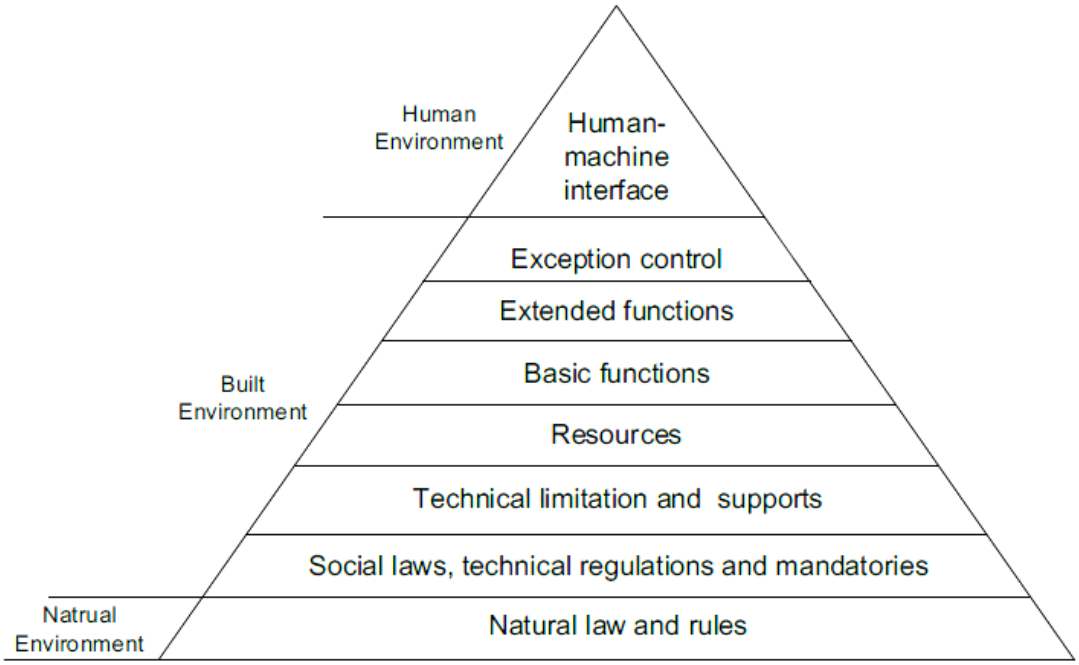


Figure 4 - Levels of product requirements and associated environments [6]

Along with this spatial classification of the product requirements, the lifecycle of a product can be used to provide a comprehensive classification of product requirements. This classification which is depicted in Figure 5 provides an appropriate context for answering generated questions for the original purpose of environment analysis.

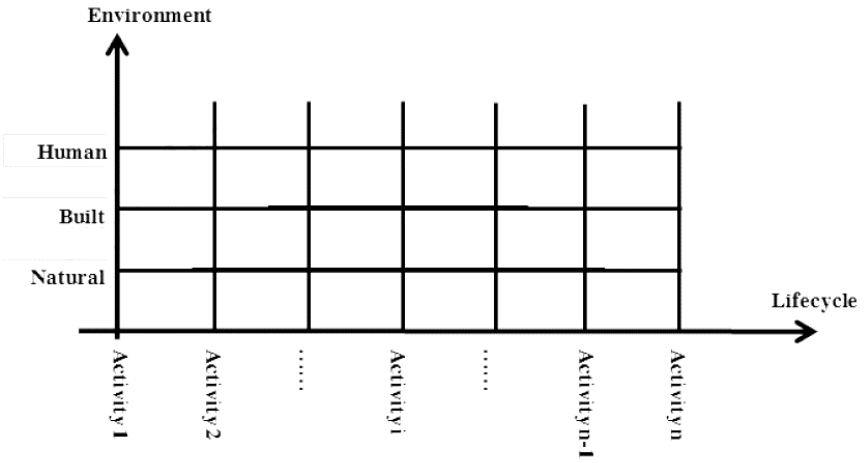


Figure 5 - Classification of product environment over its lifecycle [6]

Regarding the given context, a guideline is proposed for answering generated questions related to which considers the aforementioned context for the product and the environment. This guideline is presented in Table 4. After answering these questions, the design problem can be restated, and the ROM diagram can be updated by information obtained in this step. In Chapter 4, we will show how we use these tools to approach our research problem.

A good environment analysis should satisfy the following criteria:

1. The environment analysis should identify the right environment components and their relationships that are necessary for a given design stage.
2. The environment analysis should identify all of the environment components and their relationships that are definable at the given design stage.

So far, we have shown how a design problem can be represented by the ROM and accordingly we have introduced tools for asking right design questions and answering them to define the environment properly. After these steps, we need to prepare the available information for the next step of EBD, namely, conflict identification. For this purpose, we should introduce another step called Performance Network construction. For this purpose, we follow the steps below:

1. Extract interactions included in the design statement from the updated ROM diagram.
2. Identify relationships between interactions in the product environment system (PES).
3. Represent the interactions and their relationships as a performance network.

Table 4 - Guideline for answering design-related questions [6]

#	Question	Guideline
G1	What/ Who is N? N: a concrete, proper, or abstract noun object --- What is A N? A: an adjective constraint	a) If (A)N is the product to be designed, then the answer should address 1) the purpose of (A)N; 2) the definition of (A)N according to Figure 5-9; b) Else, if N is an environment component of a product, then the answer should define (A)N according to Figure 5 c) Else, the components and attributes of N should be described
G2	What/ Who do/ does V N? V: a Verb	For N1 that V N, the answer should define the components and attributes of N1 in the context of V
G3	When do/ does N1 V N2? --- When do/ does N1 V A N2?	The answer may assume one of the following two forms: a) In/ on a time N1 V(A) N2; b) When/ During/ While N3 V a N4, N1 V(A) N2.
G4	Where do/ does N1 V N2? --- Where do/ does N1 V A N2?	The answer may assume one of the following two forms: a) In/ Along/ Through a place, N1 V(A) N2; b) N3 V a N4, where N1 V(A) N2
G5	Why do/ does N1 V N2? --- Why do/ does N1 V A N2?	The answer should be organized as: To Va Na, N1 V(A) N2.
G6	What do you mean by V? --- What do you mean by V A? --- How do/ does N1 V N2?	a) If the subject (N1) or object (N2) of V is not the product, then the answer should include all activities included in V-ing in the context of N1 and N2; b) Else, skip the question and leave for solution generation

2.1.3. Conflict Identification

In EBD, conflict refers to an insufficiency of resources for an object to produce the desired action on its environment (active conflict) or to accommodate the object's action on its environment (reactive conflict) [6]. Undesired conflicts are driving forces of an EBD process, and they exist until they are resolved by an effective solution [1].

Performance network can help the designer to find potential conflicts by demonstrating the interactions in the environment and their relationships. We show how we perform this step

in Chapter 4. An alternative method for identifying potential conflicts based on ROM is to iteratively review the ROM diagram by rules in Table 5 for each step of the design [9].

Table 5 - Rules for identifying potential conflicts [9]

Rules	Analysis
1	If an object has multiple constraints, the potential conflict exists between any pair of constraining objects
2	If an object has multiple predicate relations from other objects, then a potential conflict exists between a pair of those predicate relations.
3	If an object has multiple predicate relations to other objects, then a potential conflict exists between a pair of those predicate relations.

2.1.4. Solution Generation

A design problem is solved when no conflict remain in the Product Environment System (PES). While identifying conflicts can show the designer the right solution direction, a basic idea supports the solution generation.

The main idea to generate a solution that resolves an existing active conflict is [6] to decompose the environment into its primitives and try to resolve the conflict by available or acquired knowledge. On the other hand, when coping with a reactive conflict, a designer must look for possible methods to optimize or rearrange existing elements or to create new elements for accommodating the interaction properly.

In this step, we start with the critical conflict which has the most influence on other conflicts, and when the conflict is resolved, it is possible that other conflicts exist or the generated solution introduce new conflicts into the environment. According to this case, this solution generation process is an iterative process.

So far, we have introduced the EBD methodology and appropriate tools and strategies for following its steps. Now we are introducing a theoretical model to the design creativity which is used in this research for studying designers while they are to cope with a design problem.

2.2. A Theoretical Model of Design Creativity

In 2012 Nguyen and Zeng proposed a theoretical model of design creativity [2] for answering two important questions in the design research:

1. "How to integrate design problem, design solutions, design knowledge, design process, and particularly designers into a design theory in a coherent manner?"
2. "How can it be possible to investigate the phenomena of design creativity, which is believed to be nondeterministic, ill-structured, and unpredictable, in a formal, structured and deterministic framework?"

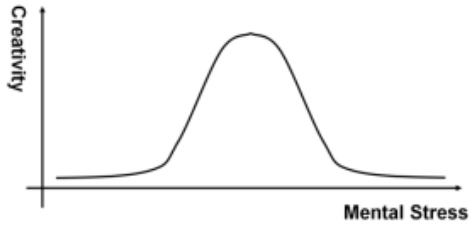


Figure 6 - Creativity and mental stress relationship curve [2]

This model associates a designer's performance on a design problem with his/ her mental capacity and the workload that the designer perceives from the assigned design problem. The mental capacity consists of knowledge and skills necessary for the designer to accomplish the task while the affect parameter referring to a designer's emotion or any mental state associated with feeling can impact the knowledge and skills at a designer's disposal while coping with a design problem.

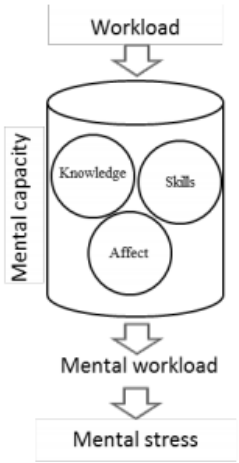


Figure 7 - Mental stress relationship with the workload and mental capacity [2]

Tan studies the effect of perception on this design creativity model and indicates that [10] perception process affects a designer's ability to use his/ her available knowledge and skills through the design process. While the theoretical design creativity model [2] and [10] studies the creativity phenomena for an individual, another study uses this model to approach describing the perception process in a design team which is working on a design problem [11]. Another study proposes a model of organizations capability [12] to describe the creativity phenomena in a team setting based on the same mental capacity model [2]. We discuss more details about these models when we propose our framework in Chapter 4.

Chapter 3

Literature Review

Designing a design team is a prominent design problem which as a first impression can be seen as different methods of hiring best people for a job. A principle in quality management advises that prevention is better than the cure which means there are issues to consider before hiring people [13] and paying close attention to selection and recruitment. Similarly, a variety of researches exists in the literature concerning the employment process; however, looking at the human resources management processes in a project, according to the Project Management Body Of Knowledge (PMBOK) [14], there are four different processes, and only two of which are concerned with acquiring the team while two others concern how to develop and manage the project team. We must not forget that an expert team is more than a team of experts and a good team is not always hired but is usually developed. In this thesis, we provide supporting tools based on Environment Based Design (EBD) for all these steps. Along with providing tools and mechanisms for staffing project teams, we focus on two latter processes which are developing and managing a project team when the team is already available.

The main research problem that this thesis addresses is to use EBD for developing a framework that can support the human resources management processes in a conceptual design project. For developing this genuine framework that supports the human resources management processes in a conceptual design process, we have used EBD methodology [1], design creativity theories [2] which we presented in the previous chapter along with the project management body of knowledge [14].

Talking about designing a design team, we should indicate underlying components of this design problem, and accordingly, we would be able to position our research on the literature and search the literature effectively for the works helping us to reach an achievement. According to the statement of this research problem, we provide the following areas of concern. Then, we indicate the most important ones and we present related literature.

In a conceptual design project, which is the context of our research, a project team is supposed to work on a design problem (problem statement) to satisfy requirements which are indicated by a stakeholder who has

defined the project and owns it. There would be a project manager who can be considered as a bridge between the stakeholder and the project team who would be responsible for accomplishing this project. We present primary elements of this problem as follow and demonstrate their relations as a context for the literature review.

1. Project Manager
2. Project Statement
3. Project Team

Each of these entities is defined and discussed in the literature, and on the other hand, they have relationships with each other as presented in Figure 8.

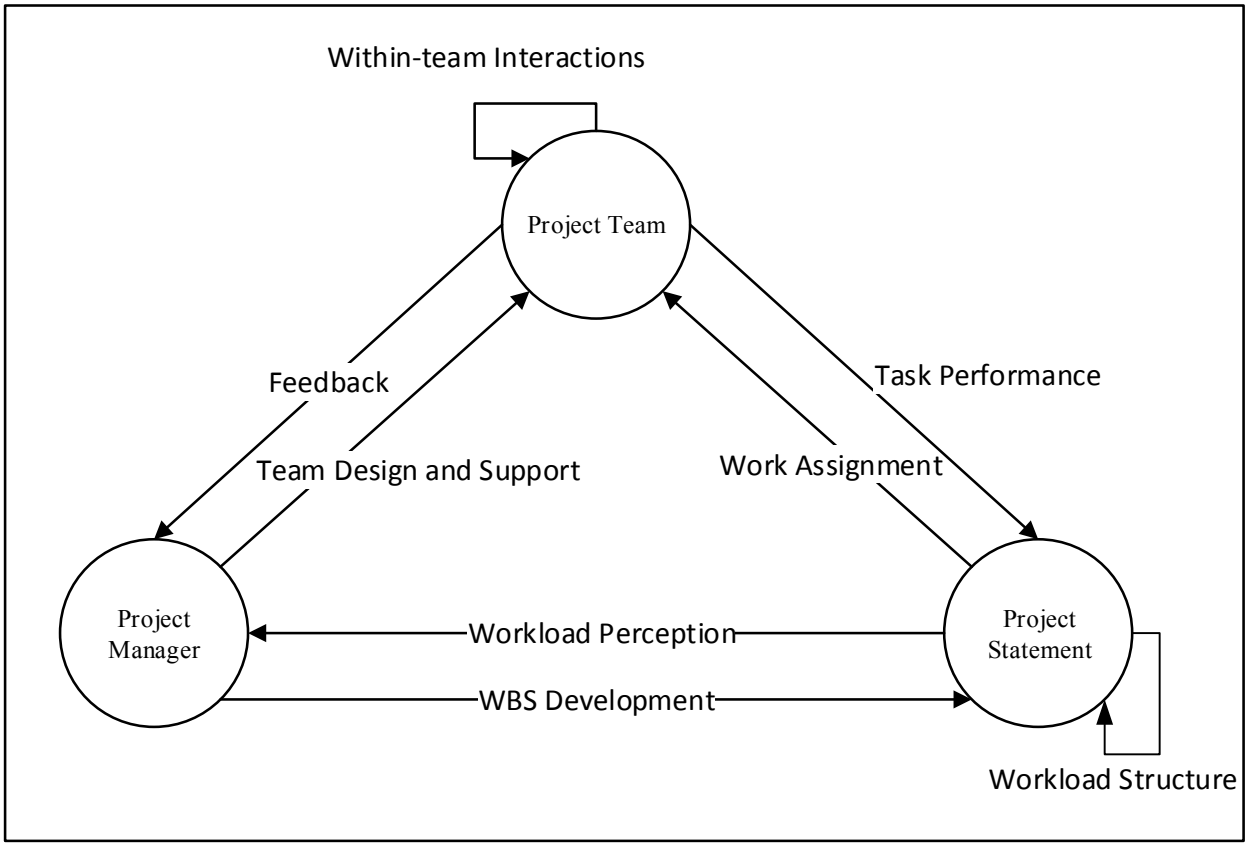


Figure 8 - Literature review context

This thesis mainly concerns the project team component of the presented context, so we mostly discuss studies related to project teams. Accordingly, we classify the literature in the two following sections.

1. Teamwork: A review of the studies on interactions within the project team and the interactions of the project team with the assigned workload.
2. Team Design: A review of the studies on interactions between the project manager and the project team through the lifecycle of the project.

3.1. Team Design Literature

3.1.1. Team Definition

There exist various definitions for teams. We have reviewed a few of most-referred definitions in the literature, and we are using a definition of teams as followed. A team is a distinguishable collection of individuals who are interdependent in their tasks, who share common goals, they are embedded in an organizational context regarding which the team maintains its interactions with other units. This definition complies with definitions provided in [15] and [16]. Cohen [15] introduced four types of teams including parallel teams, project teams, work teams and management teams. Given we are defining our problem in the context of a design project, team members are at least assigned to a project which is defined for a concrete purpose, and they are team members while the project exists. Thus, our definition complies with [17] as well which assumes that team members are each assigned specific roles or functions to perform and they have a limited life-span of membership.

3.1.2. Team Design

Cohen and Bailey [15] defined design factors as "those features of the task, group, and organization that can be directly manipulated by managers to create the conditions for effective performance." They also categorize team design factors within group composition, task features, and organizational context. This definition is widely accepted in the literature (e.g. Wagerman 2001, Stewart 2006, Carter 2018) [18] [19] [20]. In line with this definition, [21] refers to team design factors as "specification of team membership; definitions and structure of a team's tasks, goals and members' roles; and the criterion of organizational support for the team and link to the broader organizational context." These factors or features can be accounted as inputs for the commonly accepted framework of teams which includes input-process-output (e.g. Hackman, 1987 [22]) introduced by McGrath in 1964 [23].

3.1.3. Team Composition

A related but somewhat different area of research looks at how Literature refers to team composition as the mix of individuals included in the team [19]. The research on team composition is primarily concerned with one main question: how does the heterogeneity of individual characteristics relate to team outcomes?

Studying diversity in teams can help to understand them and to build teams for design success. One must be careful about this kind of research since observing teams over a long period of time may indicate different findings rather than a short period of time, and it can also help for finding out more about these relationships. A study at Stanford University on diversity in design team initially suggests that [24]. In their initial study, they find out that the beneficial diversity in teams is mostly related to variety in cognitive styles and problem-solving approaches. Kress [25] indicates overall cognitive diversity does not appear to correlate with overall team project performance and they find out more details about this relationship. This can show how over time researchers can tell more details about these relationships with more evidence.

Many researchers have worked on this kind of research and found statistically significant correlations between team performance and a vast variety of team design factors although in some cases different results can be observed in different settings of experiments. During recent years, many studies of this kind, in the literature mentioned the mixed results diversity effects on team performance, e.g. [26] [27] [28]. Bell mentions that according to the available literature on team composition it is unclear which specific characteristics and configurations of these characteristics can be used for selecting and placing people in teams to increase team performance [27]. In this regard, meta-analytic studies seem more reliable, which have studied many experiments, however, in some cases, reasons behind these relations still remain a question.

Bell provides a meta-analytic [27] in order to help designers for considering specific composition variables which have a significant impact on team performance. It suggests that in many studies team performance is correlated with general mental ability or emotional intelligence of the team. In 2007, Horwitz analyzed 14 studies and found out that [26] task-related diversity positively impacts the team performance while the biogeographic-diversity is not significantly related to the performance quantity and quality. They have assumed three levels for task complexity, and the project-type task is accounted for as a highly cognitive task. They have concluded that team diversity in the context of Cox and Blake's diversity paradigm [29] can potentially provide competitive advantages to organizations. Given these results, selecting the right team for a project mostly depends on the project definition and the most valuable characteristic to be considered should be required cognitive and emotional capacities. On the other hand, companies in developed countries are subject to equal opportunity employer which make them uninterested in implications of many of these studies which are concerned with demographic and personal characteristics rather than cognitive ones.

In 2014, Mathieu reviewed team composition models and categorized them into four models [28] as follows:

- Traditional personnel-position fit model (Individual model with a focus on individuals)
- Personnel model with teamwork consideration (Individual model with a focus on the team)

- Relative contribution model (Team model with a focus on individuals)
- Team Profile model (team model with a focus on teams)

They provide an integrative framework to develop a comprehensive model which encompasses all four approaches. One important consideration for their new model is that they consider membership dynamics account when people join or leave the team. They account temporal effects factor in their model which can calculate team effectiveness for a particular temporal period.

3.1.4. Simulation Models for Studying Team Design

The most-practiced research design in the team design literature as presented so far is to observe a team which is performing on assigned tasks while the researcher studies team outcomes under different circumstances made by manipulating design factors. Researchers commonly conduct these studies in a lab-setting or field setting, but there is another approach to study the phenomena by simulation models. In simulation-based approach, there is no actual team and simulation models are accountable for producing outcomes instead of teams. Simulation models are appropriate for studying teams who are dealing with routines. We review the Virtual Design Team (VDT) model [30] which can be credited as the most important work of this approach.

The virtual design team is a model which is able to model planned teams and organizations and analyze their work before actually building them up to work. In each project, stakeholders are interested to find the answer to questions such as below and usually project managers must be able to answer them:

- Is the planned team capable of finishing the project within a given timeframe while meeting specific qualities?

- How and to which extent can changes in the planned team affect specific measures of a project?

The VDT model is basically built on the fact that organizations are fundamentally information-processing structures. Organizations are composed of teams trying to achieve specific tasks. People in such an organization are responsible for processing information and collaborating within and between teams relying on their information processing capacity. Organizational participants use formal communication channels for sending and receiving processed information as messages.

For each task assigned to an actor, the VDT model assigns a processing speed and a verification probability failure. This assignment is based on the match between the complexity of the activity and capability of the assignee. Actors are modelled in VDT based on their capability, attention rules, action and organizational role. Actor model in VDT represents the following parameters:

- Actor size (number of people)

- Actor skill and skill level
- Responsibilities (activities)
- Role in the organization
- Task experience (High, Medium, Low)

The object of activity analysis in VDT is multiple individual actors and their assigned activities which are derived from the whole organization and one high-level task. Actors in a project team exchange information via communication channels in order to coordinate. VDT is trying to model social science theories. They claim to observe consistency among the experimental results, predictions of the theory, experienced project managers and simulations.

Some researchers took the simulation approach for solving the team design problem like [31] in which authors use simulation to try different team characteristics to suggest optimum team setting according to properties of a design problem. Team settings are quantified by team size and interaction frequency. Teams with the right characteristics perform more effectively than the mere sum of the constituent team members. However, teams with the wrong characteristics may function much less effective than the sum of individuals in certain situations. They have also conducted a cognitive study to test the predictive equations for validating their model [31].

Since team design research is interdisciplinary research, we can expect conflicting opinion among scholars from different backgrounds. Thus, it is not surprising that some researchers from non-engineering backgrounds argue the validity of simulation models. Marks [32] discusses the simulation approach pros and cons in the team research and mentions while this is helping the research in terms of technology to simulate results, the researcher must be patient about the artificial environment of the experiment and the simulation and she should not neglect the theory behind the model. It is not always possible to simply generalize the study findings from the research environment to real-world environments and researchers must be aware of this issue. The context in which a researcher is interested in generalizing the findings of his/ her research is not possible to be simulated over a long term since the simulation models are not capable of anticipating all the changes and consequences in the environment.

3.1.5. Dynamics in the Team Design Problem

Most of the studies in presented literature are results of a short term observation of teams concerned about inputs in the IPO framework of teams and they refer to team design factors as those which can be decided before the team starts to work. Bell [27] refers to team design as a stage of team management in which authorities do activities such as selection and placement which is true but designing a design team is much more than an input before the team starts to perform. Some studies approach the team design problem,

There are more activities which can be considered as team design problems when we are trying to design a team effective for the purpose. Wageman [18] defines team design as a type of team leader's activity to establish specific features including team purposes, structures, or organizational contexts aiming to improve performance effectiveness. In addition, Wageman [18] studies another type of leader's activity as well which is providing hands-on coaching. It shows that design and coaching activities both affect team performance and they also interact with each other. Additionally, the positive impact of coaching is more significant in well-designed teams while ineffective coaching has undermined their performance less. Thus, for designing an effective team one can go further than selection and placement and think about coaching and leadership in terms of collaborations between the project team and team manager.

In terms of considering interactions between workload and project team, Morgeson [21] proposes an integrative method for designing work that accounts the team design by considering a variety of workers' characteristics across task, social, and contextual domains. This valuable framework can be used for integrating work and workers in a variety of teams; however, in our problem that we are dealing with a design problem which is usually assigned by a client, we are unable to incorporate this model because of the creative and innovative nature of design. Nevertheless, they provide a set of worker's characteristics which can be used for appropriate assignment of candidates to projects. They list performance quantity and quality under key outcomes of work design as a result of considering some certain worker's characteristics for designing appropriate work.

Considering the IPO framework for teamwork, we see some works in the literature trying to address something more than only inputs. There is a fact that putting experts together does not guarantee an expert team [33] and there are parameters which influence existing teamwork processes leading to a better performance. Hiring an appropriate team is essential but not sufficient. As we are designing a team, we are interested in considering these parameters in a systematic order. Using a design methodology like Environment Based Design (EBD) can support this effort as it supports the design process over the lifecycle of the product. In our case, the lifecycle of the team is concerned, and we will discuss it in Chapter 4. In a project manager's perspective, the PMBOK practice is widely practiced for supporting projects, and its knowledge area of human resources [14] is mainly concerned with project teams. Thus, we are interested in proposing a comprehensive framework which is compatible with PMBOK as well.

In a literature review study on team effectiveness [34] shortcoming of traditional research in teams are presented. Regarding more complex organizational structures of today, especially in project-based organizations, many of the inputs which are accounted in the IPO framework may become dynamic. As examples for more clarification, team members may join the team or leave, planned or unplanned or even be relocated within the organization because they were unexpectedly needed elsewhere. The team itself may

be divided into individual or subgroups at some points. The team may face new challenges, especially in complex and innovative design projects. These are complexities which are mostly unobserved in the literature. They suggest new qualitative and quantitative research to be done toward studying new arrangements of teams. To some extent, we are proposing ideas for coping with these dynamics in a design project. According to the context Figure 8, these dynamics can happen within a team as well as a change in the workload. We propose an idea for coping with dynamics which can happen in team members; we will provide a descriptive model that can be employed by the project manager for resolving those conflicts.

3.2. Research Position

We introduced current literature on team design based on a widely accepted Input-Process-Output (IPO) framework of teamwork [23]. We presented how scholars are approaching to manipulate framework inputs for finding optimal team characteristics for more effective performance to produce the desired output. Some works (e.g. work design, coaching) [35] [18] have put efforts for integrating other aspects of the presented context (Figure 8) within the team design problem. We are using Environment Based Design (EBD) [1] methodology as a systematic approach to the team design problem throughout project team's lifecycle within IPO framework in a way which is consistent with project management practices [14]. Furthermore, we propose a framework, and we also consider its compatibility with some dynamics in a team through the lifecycle as suggested by Mathieu [28], [34].

Chapter 4

The Proposed Framework

In this chapter, we use the Environment Based Design (EBD) methodology to approach the team design problem. We investigate whether EBD can be used for designing a framework that supports human resources management processes for conceptual design projects effectively. In this chapter, we follow EBD steps as introduced earlier including "environment analysis," "conflict identification" and "solution generation." One important aspect of EBD which is worth mentioning is the recursive logic that makes a design problem evolve through this process relying on solutions. Thus, we try to formulate the design problem to the best of our knowledge, but we can define it best at the end of the process.

4.1. Environment Analysis Step for Staffing Framework Design

In this section, we start by the ROM diagram of the design statement and conduct the environment analysis for the design problem.

4.1.1. ROM Formulation of the Design Problem

The first step in design is to present the design problem formally. In this stage of EBD, we state the design problem verbally, so we can start modelling the design problem statement with the ROM diagram tool and start the environment analysis stage. The design problem statement is as follows:

"Design a staffing framework to staff conceptual design projects effectively by design teams."

Now, according to the EBD methodology which we have employed for this design problem, we model the design problem statement as a ROM diagram, in Figure 9. This diagram shows the existing concepts in the environment and their relationships with each other as well as their relationship with the product that we are designing.

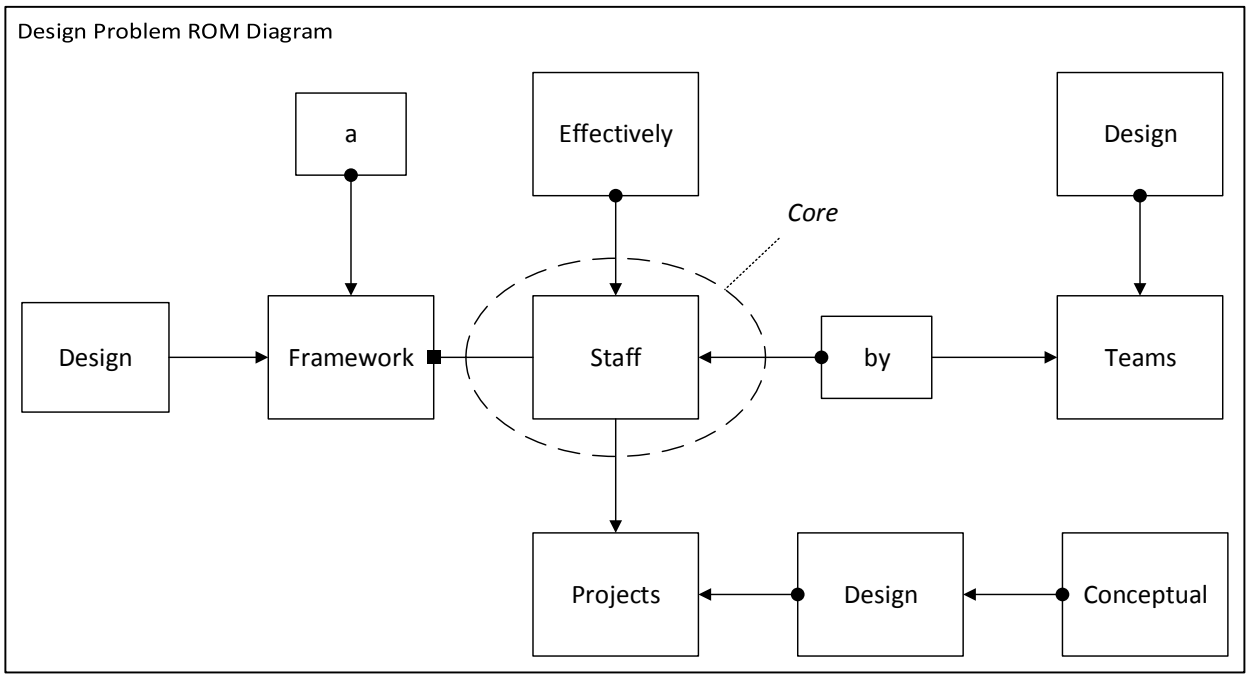


Figure 9 - ROM diagram for the initial design problem statement

4.1.2. Asking the Right Questions

Now, we must apply the rules for generating questions to this diagram in order to develop our question base. These are general questions that are generated for the first round of our analysis and answering them will make the problem clearer. The "Framework" object in the diagram is the product, so according to the rules, we ask questions about it last. The most constrained object is "Staffing," so it must be clarified first. Before defining this object, we need to define the constraining objects first. Following these rules for generating questions, we come up with the set of questions which are shown in Table 6.

Table 6 - Questions generated from ROM diagram according to the template

#	**Object and Condition**	**Question**
Q1	Project [T1] [Proper noun]	What is a "project"?
Q2	Conceptual Design Project [T3] [Constraining proper noun]	What is a "conceptual design project"?
Q3	Design Team [T1] [Proper noun]	What is a "design team"?
Q4	Framework	What is a "framework"?

	[T1] [Noun] [Product]	
Q5	Framework effectively staffs design project [T5] [Verb] [Product Function]	Why does the framework effectively staff design project?
Q6		What do you mean by "staffing effectively"?
Q7	Framework[N1], Effectively[A], Staffs[V], Design Project [N2]	When does the framework staff design project effectively?
Q8		Where does the framework staff design project effectively?
Q9		How does the framework effectively staff design project?
Q10	Design [T6][Verb]	Who will design the framework?

4.1.3. Answering Questions with the Right Approach

The next step for the environment analysis is answering the questions which are generated. As designers, we may look in the dictionary, on the internet or to other knowledge bases to provide the answers [7]. In the case that there is a specific client for the design project, then answers can be collected from the stakeholders as well. In cases in which the object has a broad definition, we must make sure that we are providing the answer in the appropriate context. Thus, we provide the answers according to the guideline that we have for answering questions and which we have presented in Chapter 2. We have answered the questions above and presented answers in Table 7.

Table 7 - Answering generated questions according to the answering guideline

#	**Question**	[Guideline] **Answer**
A1	What is a "*project*"?	**[G1/C]** A temporary endeavour undertaken to create a solution in response to some specific requirements. The project has a lifecycle of Initiation, Planning, Execution, Monitoring, Closure [14]
A2	What is a "conceptual design project"?	**[G1/B]** Conceptual design is a description of how a new product will work and meet its performance requirements [36]. A conceptual design project is a temporary endeavour undertaken to describe how a product work to meet its requirements (functions and form)

A3	What is a "design team"?	**[G1/B]** A team is a distinguishable collection of individuals who are interdependent in their tasks, who share common goals, they are embedded in an organizational context regarding which the team maintains its interactions with other units. Teams have a lifecycle of forming, storming, norming, performing and adjourning [37]. A design team is a group of individuals who work together for designing a product to satisfy some requirements. Individuals with various knowledge and skills are required to undertake design tasks. A design team is formed at the beginning of the design, they perform on the design problem interdependently, and the team is disassembled upon project completion. Teams may experience dynamics within their lifecycle in various terms.
A4	What is a "staffing framework"?	Framework definitions according to dictionaries: • a set of ideas or facts that provide support for something [38]. • A framework is a particular set of rules, ideas, or beliefs which you use in order to deal with problems or to decide what to do [39]. • A system of rules, ideas, or beliefs that is used to plan or decide something [40]. • A basic structure underlying a system, concept, or text [41]. Staffing definitions according to dictionaries: (transitive verb) • Provide (an organization, business, etc.) with staff [42]. • to supply (an organization or business) with workers [43]. The **purpose**: The purpose of staffing framework is to provide a set of processes and ideas to support the staffing process for a project in terms of planning and decision making. Staffing refers to providing the design project with appropriate staff.

		the **lifecycle** of project staffing is as follows in compliance with PMBOK [14]: Identify project staff requirements Acquiring an appropriate project team Developing the project team Managing the project team Environment **components** through the staffing lifecycle are presented in Figure 10.
A5	Why does the framework staff teams effectively?	**[G5]** To provide and maintain an appropriate team [human resources] for accomplishing the project, framework staffs teams effectively
A6	What do you mean by "staffing design projects effectively by design teams"?	**[G6/B]** Skip the question and leave for solution generation. (We answer this question in section 4.3)
A7	When does the framework staff teams effectively	**[G3]** Before the project starts and throughout the project until it is accomplished.
A8	Where does the framework staff teams effectively?	**[G4]** Framework staffs a team for a conceptual design project.
A9	How does the framework effectively staff design projects with design teams?	**[G6/B]** Skip the question and leave for solution generation. (We answer this question in section 4.3)
A10	Who will design the framework?	**[G2]** Designers use technical resources and design tools to design the framework.

4.1.4. Staffing Lifecycle

According to the context of our problem, the staffing lifecycle is ongoing throughout the the project. Since each project has its own requirements, it needs its own type of workforce who are competent to perform the related underlying tasks. For effective staffing, we need to start by analyzing the project statement to breakdown the workload into smaller work units whose required competencies for accomplishment are easily identified. After identifying required people and finding them for doing underlying works, we need to focus on assigning them to the project; this process is commonly referred to as recruitment. Usually, it does not end here, and you cannot expect someone just to join the project team and perform perfectly. Thus,

the development of the team is another aspect of the project. This way, we have the required team for accomplishing the project, and we have developed the team members to make sure they have access to the resources they may need. Another step that makes the crucial distinction between individual performance and team performance is the nature of teamwork which may cause team dynamics such as conflicts. This step in the PMBOK is referred to as team management and managing the appropriate team in this manner can almost guarantee the satisfying performance of the team.

Referring to this discussion which complies with the PMBOK human resources management processes and would also be valid in our case since we are approaching the problem in a project context, we will list the lifecycle of the staffing problem as follows:

1. Project Staffing Plan Development
2. Project Team Acquisition
3. Project Team Development
4. Project Team Management

	Team Planning	Team Acquisition	Team Development	Team Management
Human	Project Manager	Project Manager	Project Manager	Project Manager
	Stakeholder	Stakeholder	Stakeholder	Stakeholder
		Available pool of candidates	Team memebers	Team members
			Team	Team
Built	Project Statement (Workload)	Project Statement (Workload)	Project Statement (Workload)	Project Statement (Workload)
	WBS	WBS	WBS	WBS
	Work Units	Work Units	Work Units	Work Units
	Time Budget	Time Budget	Time Budget	Time Budget
	Cost Budget	Cost Budget	Cost Budget	Cost Budget
		Other Available projects	Design Artifacts	Design Artifacts
			Design Ideas	Design Ideas
			Mental Models	Mental Models
			Shared Mental Models	Shared Mental Models
Natural	Uncertainity	Uncertainity	Uncertainity	Uncertainity
			Team Member Affect	Team Member Affect
			Individual Perception of Workload	Individual Perception of Workload
			Individual Perception of Team	Individual Perception of Team
			Shared Perceptions of Workload	Shared Perceptions of Workload
			Shared Perception of Team	Shared Perception of Team
				Team Conflicts
				Team Dynamics

Figure 10 - Analysis of the environment components

"Design a staffing framework to staff conceptual design projects effectively by design teams."

According to the answers which are gathered, we can restate the design problem in a way in which the environment is more clarified.

"Designers will design a framework that staffs conceptual design projects by design teams. The framework supports the project manager in planning and decision making through the staffing lifecycle. Stakeholders assign a certain project statement to the project manager within an organization. According to project requirements, the project manager selects the appropriate team by selecting them from the available pool of individual candidates within the organization. The project manager assigns tasks to team members. The project manager develops the team according to his/her evaluation of the team along with project requirements. Team members' performances are affected by their feelings about the workload and teamwork. The Project team performs on the workload based on their perception of the workload. Team members create design concepts. Team members evaluate design concepts. The project manager evaluates design concepts. Stakeholders evaluate design concepts. Mental models represent the individual perception of team members on the workload (task) and the team. Team members share perceptions to some extent. Conflicts arise in the project team because of differences in perceptions of task, team or process among team members [44]. The project Manager helps the team to resolve conflicts."

4.1.5. Analyzing Interactions Available in the PES

According to the answers we have provided and components of the environment that we have indicated through the staffing lifecycle (Figure 10), we have elicited interactions in the Product Environment System (PES) which are provided in Table 8.

Table 8 - Interactions available in the Product Environment System (PES)

#	**Interaction**	**Interaction Parties**	
I1	Designers design a staffing framework	Designer	Framework
I2	The framework supports project manager through the staffing lifecycle	Framework	Project Manager
I3	Project manager uses the staffing framework	Project Manager	Framework
I4	Stakeholder assigns a certain project statement to project manager	Stakeholder	Project Manager
I5	Project manager defines project requirements	Project Manager	Workload
I6	Project manager selects from the available pool of individual candidates	Project Manager	Individual
I7	The project manager provides an appropriate team	Project Manager	Design Team
I8	The project manager maintains the appropriate team	Project Manager	Design Team
I9	Project manager assigns tasks to team members	Project Manager	Team Member

I10	Project team perform on the workload	Team Member	Workload
I11	Team members' Perceptions of the workload affect their performance	Perception	Performance
I12	Project team perform within an organization	Design Team	Organization
I13	Team members' Perceptions of the working environment affect their performance	Perception	Performance
I14	Team members work in a team setting	Team Member	Design Team
I15	Team members share perceptions to some extent	Team Member	Team Member
I16	Mental models represent individual's perception	Mental Model	Perception
I17	Conflicts arise in the project team	Team Member	Team Member
I18	Team members create design concepts	Team Member	Performance
I19	Team members evaluate design concepts	Team Member	Performance
I20	Project manager evaluates design concepts	Project Manager	Performance
I21	Stakeholders evaluate design concepts	Project Manager	Performance
I22	Project manager evaluates team	Project Manager	Design Team
I23	Project manager develops team	Project Manager	Design Team
I24	Project Manager helps the team to resolve conflicts.	project manager	design team

4.1.6. Performance Network of Interactions

Investigating the causal relationships between the above-mentioned interactions results in the matrix which is presented in Table 9. We have removed some interactions since we could not investigate any causal relationship between them and our PES. Thus, we will remove them from our matrix and set of interactions, and we will discuss them and their associations with our design problem further. In our problem, we have removed I11, I13, I16 and we will discuss them later.

Table 9 - Causal relationships matrix for PES interactions

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I12	I14	I15	I17	I18	I19	I20	I21	I22	I23	I24
I1	0	**0**	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I2	1	**0**	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I3	0	**1**	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I4	0	**0**	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I5	0	**1**	**1**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I6	0	**1**	**1**	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
I7	0	**1**	**1**	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
I8	0	**1**	**1**	0	1	1	1	0	0	1	1	1	0	0	0	0	1	0	1	0	0
I9	0	**1**	**1**	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
I10	0	**0**	**0**	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
I12	0	**0**	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

I14	0	0	0	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
I15	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
I17	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0
I18	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
I19	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
I20	0	1	1	1	1	0		0	1	0	0	0	0	0	1	0	0	0	0	0	0
I21	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
I22	0	1	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
I23	0	1	1	1	1	0	1	1	1	1	0	1	0	0	0	0	1	0	1	0	0
I24	0	1	1	1	0	0	1	1	0	0	0	1	0	1	0	0	1	0	1	0	0

4.1.7. Analyzing the Performance Network

We analyze this interactions matrix as the structure of the interactions network to find potential conflicts in the Product Environment System (PES). In this way, we analyze the interactions in terms of their incoming and outgoing arrows in the graph which is presented in Table 10:

Table 10 - Performance network analysis

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I12	I14	I15	I17	I18	I19	I20	I21	I22	I23	I24
Inputs	1	19	18	10	7	4	5	2	5	4	4	7	0	1	3	1	3	0	4	0	0
Outputs	0	1	1	0	5	7	7	12	8	3	0	6	1	3	2	2	8	2	6	13	11

It is worth mentioning that interactions which are dependent on I2, I3 can demonstrate the use cases of the staffing framework which can be used by the project manager to support the project success.

4.2. Conflict Identification

From this performance network analysis, we get some initial ideas about potential conflicts. The nodes (interactions) without any incoming arrow indicate shortcomings in resources for accommodating the interaction. On the other hand, nodes without any outward arrow available show the lack of response for some interactions. In the next step, we can analyze those nodes with a higher number of outgoing arrows than incoming arrows.

To accommodate interactions which are available in the PES resources are required. Basic resources for accommodating interactions include time in terms of which we should refer to the lifecycle of the staffing process. We have also used the lifecycle of the staffing process for analyzing and describing our PES. We have indicated the required resources along with the lifecycle's steps in Table 11

Table 11 - Resources in the Product Environment System (PES)

#	Resource Name	Category
R1	Framework	Framework
R2	Framework Designer	
R3	Organization	Human
R4	Project Manager	
R5	Stakeholder	
R6	Individuals	
R7	Design Team	
R8	Team Members	
R9	Workload	Built
R10	Design Concepts and performances	
S1	Planning	Lifecycle
S2	Acquisition	
S3	Development	
S4	Management	

Lack of resources for accommodating interactions can result in conflicts within the PES. Thus, the analysis of required resources for interactions can help for identifying and resolving conflicts whether active or reactive. Table 12 shows the available resources necessary for accommodating each interaction in the PES. Table 13, shows which interactions are using each resource are indicated. This analysis can demonstrate the interactions' competitions over certain resources that can result in reactive conflicts.

Table 12 - Resources used for accommodating interactions in the PES

Interactions	**Framework**		**Human**						**Built**		**Lifecycle**			
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	S1	S2	S3	S4
I1	**0**	1	0	0	0	0	0	0	0	0	N/A			
I2	**1**	0	0	0	0	0	0	0	0	0	1	1	1	1
I3	**1**	0	0	1	0	0	0	0	0	0	1	1	1	1
I4	**0**	0	0	1	1		0		1	0	1	0.5	0.5	0.5
I5	**1**	0		1	0		0		1	0	1	0	0	0

I6	**1**	0	1	1	0	1	0	0	0	0	0	1	0	0
I7	**1**	0	1	1	0	0	1	1	0	0	0	1	0	0
I8	**1**	0	1	1	0	1	1	1	0	1	0	0	1	1
I9	**1**	0		1	0	0	1	1	1	0	0	1	0	0
I10	**0**	0		0	0	0	1	1	1	0	0	0	1	1
I11		0				0			1	1				
I12	**0**	0	1	0	0	0	1	1	0	1	0	0	1	1
I13		0				0			0	1				
I14	**0**	0	1	0	0	0	1	1	1	0	0	0	1	1
I15	0	0		0	0	0	1	1	1	1	0	0	1	1
I16		0				0								
I17	**0**	0		0	0	0	1	1	1	1	0	0	0	1
I18	**0**	0		0	0	0	0	1	1	1	0	0	1	1
I19	**0**	0		0	0	0	0	1	1	1			1	1
I20	**1**	0		1	0	0	0	0	1	1			1	1
I21	**0**	0		0	1	0	0	0	1	1	0	0	0	0
I22	**1**	0		1	0	0	1	1	1	1	0	0	1	1
I23	**1**	0		1	0	0	1	1	1	1	0	0	1	0
I24	**1**	0		1	0	0	1	1	0	1	0	0	0	1

Table 13 - Interactions using each available resource in the PES

	Resource	**Interactions**
R1	Framework	I2, I3 I5, I6, I7, I8, I9 I20, I22, I23, I24
R2	Framework Designer	I1
R3	Organization	I6, I7, I8 I12, I14
R4	Project Manager	I3, I4, I5, I6, I7, I8, I9

		I20, I22, I23, I24
R5	Stakeholder	I4 I21
R6	Individuals	I6, I8
R7	Design Team	I7, I8, I9, I10 I12, I14, I15, 17 I22, I23, I24
R8	Team Members	I7, I8, I9, I10 I12, I14, I15, 17, I18, I19 I22, I23, I24
R9	Workload	I4, I5 I9, I10, I11 I14, I15 17, I18, I19, I20, I21, I22, I23
R10	Design Concepts and performances	I8 I11, I12, I13, I15 17, I18, I19, I20, I21, I22, I23, I24
S1	Planning	I2, I3 I4, I5
S2	Acquisition	I2, I3 I6, I7, I9
S3	Development	I2, I3 I8, I10, I12, I14, I15 I18, I19, I20 I22, I23
S4	Management	I2, I3 I8, I10, I12, I14, I15 I17, I18, I19, I20 I22, I24

For a more legible presentation, given that the project is done chronologically, we present the conflict network in four distinct temporal phases as below:

Phase Number	Phase	Conflicts Network
Phase 0	Framework Design Phase	Figure 11
Phase 1	Project Planning Phase	Figure 12
Phase 2	Project Performance Phase	Figure 13
Phase 3	Project Delivery Phase	Figure 14

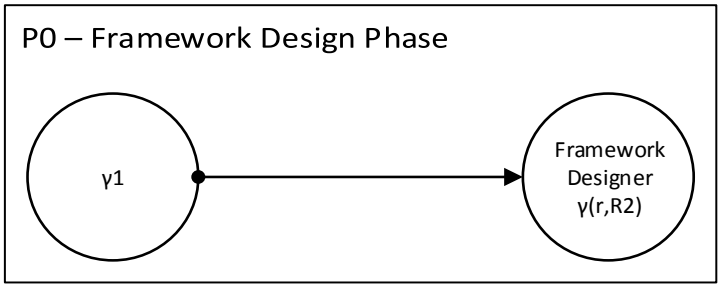


Figure 11 - Conflicts network for Phase 0

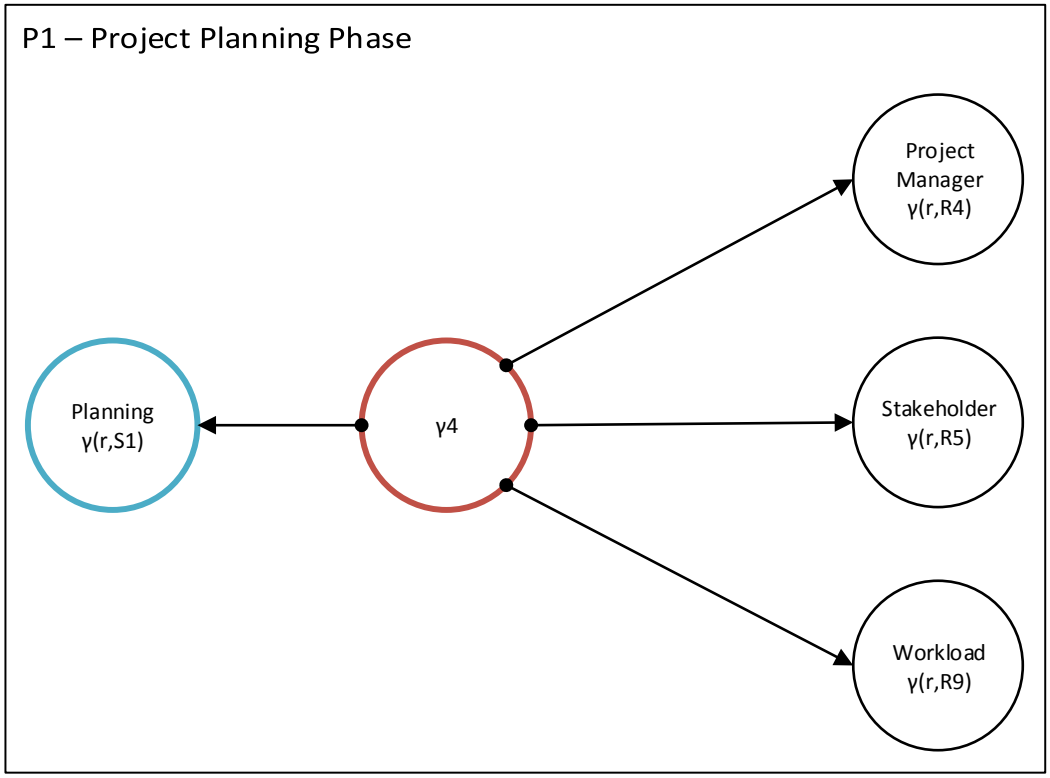


Figure 12 - Conflicts network for Phase 1

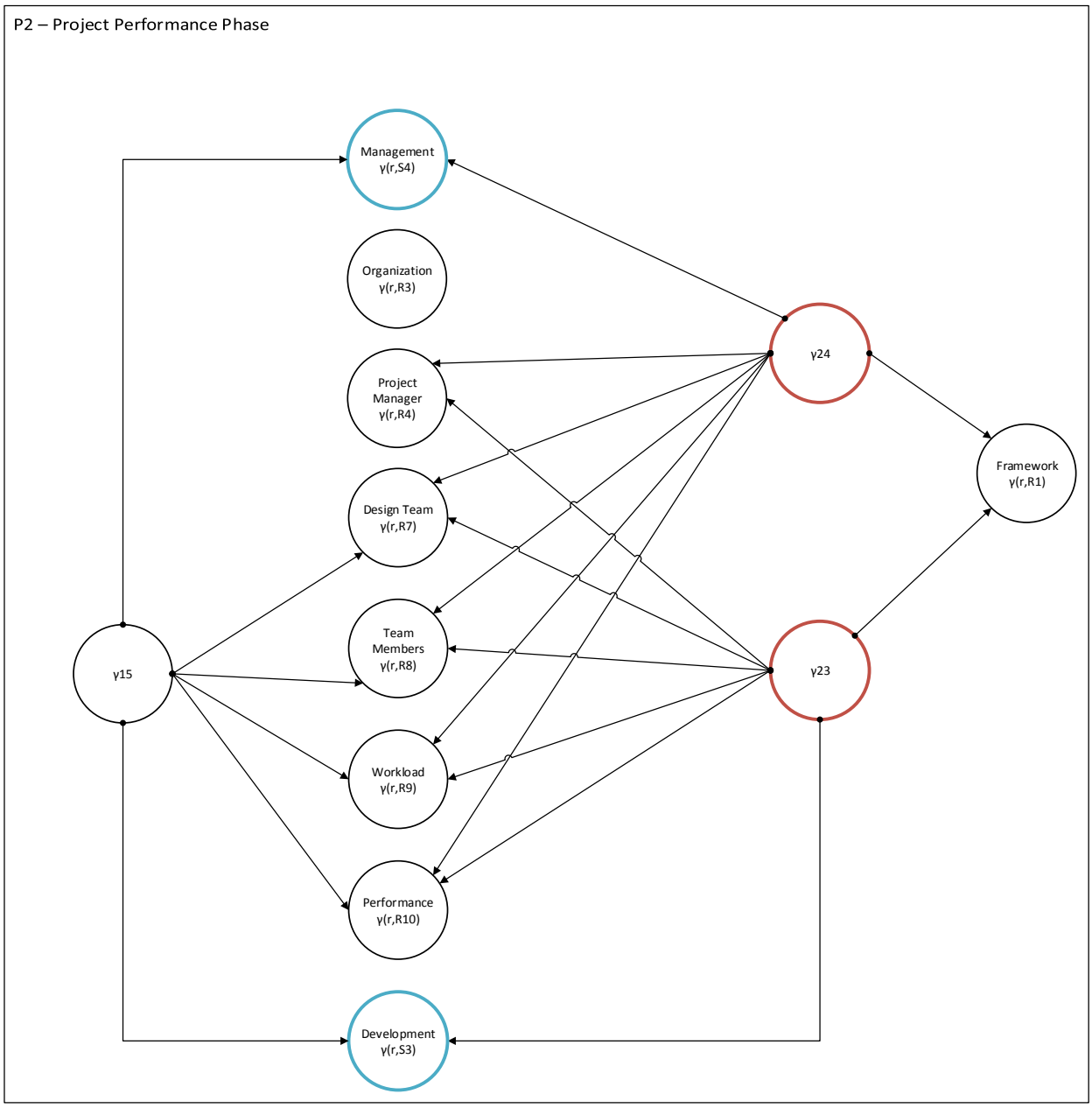


Figure 13 - Conflicts network for Phase 2

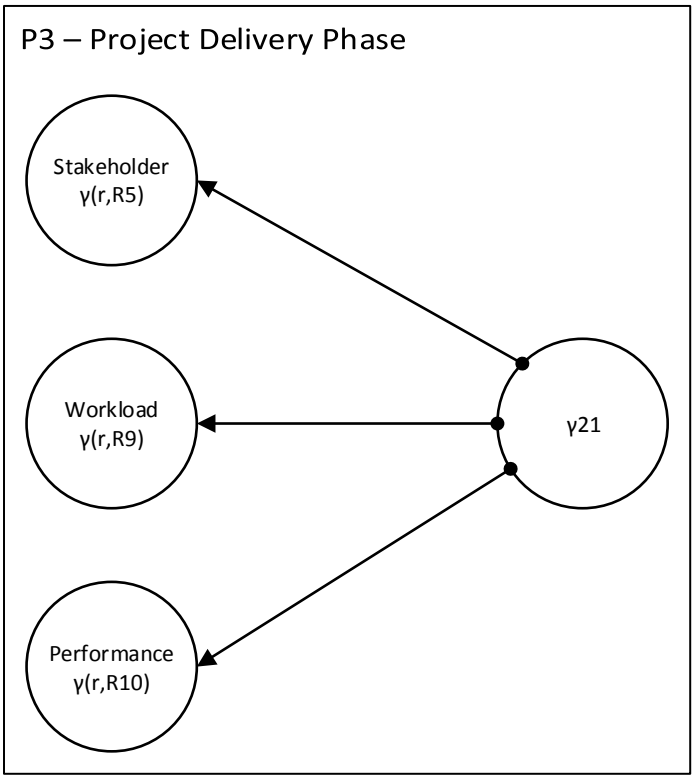


Figure 14 - Conflicts network for Phase 3

4.2.1. Active Conflicts

An active conflict refers to a lack of action for a needed response [1], [9]. In a performance network, nodes without any incoming arrow can be sources of active conflicts. According to the dependency matrix for PES and the presented analysis, these interactions which cannot be accommodated because of a lack of action are as follows in our PES:

According to the performance network, we may have active conflicts for the following interactions:

- I15 - Team members share perceptions to some extent
- I21 - Stakeholders evaluate design concepts
- I23 – The Project manager develops the team
- I24 – The Project Manager helps the team to resolve conflicts.

In terms of causal relationships, a node without any incoming arrow means that such interactions do not depend on any other interaction in the PES to occur. It means that there is no cause available for the nodes without any incoming arrow in the PES, and in case they need one, we need to provide it by resolving

conflicts. For now, we keep this for active conflicts and proceed to construct the conflicts network for our design problem.

Analysis of Active Conflicts

After investigating potential active and reactive conflicts, we construct the conflict network of our design problem

The incidence matrix for this network is presented in Table 14 which indicates relationships between active conflicts and reactive conflicts. This matrix is the basis of the performance network which is presented in Figure 13.

Table 14 - Incidence matrix for active conflicts and resources network

	γ 15	**γ 21**	**γ 23**	**γ 24**
R1			1	1
R2				
R3				
R4			1	1
R5		1		
R6				
R7	1		1	1
R8	1		1	1
R9	1	1	1	1
R10	1	1	1	1
S1				
S2				
S3	1		1	
S4	1			1
#Conflicts	**6**	**3**	**7**	**7**

According to the information above, we present the analysis of this network in Table 15.

Table 15 - Analysis of active conflicts

ID	Interaction	Type	Available resources	Critical
γ_{24}	Project Manager helps the team to resolve conflicts.	Active	R1, R7, R8, R9, R10	Yes
γ_{23}	Project manager develops team	Active	R1, R4, R7, R8, R9, R10	Yes
γ_{15}	Team members share perceptions to some extent	Active	R7, R8, R9, R10	No
γ_{21}	Stakeholders evaluate design concepts	Active	R5, R9, R10	No

This analysis indicates that γ_{23} and γ_{24} are critical conflicts which should be resolved in the solution generation step.

4.2.2. Reactive Conflicts

A reactive conflict is a lack of resource to accommodate an action in the PES. A reactive conflict refers to insufficiency of resources to accommodate an object or the responses from the object.

According to the performance network, we have reactive conflicts for the following interactions:

- I1 - Designers design a staffing framework
- I4 - Stakeholder assigns a certain project statement to the project manager
- I12 – The Project team performs within an organization

Analysis of these conflicts is provided in Table 16.

Table 16 - Analysis of reactive conflicts

ID	Interaction	Type	Available resources
γ_{12}	Project team perform on the task within an organizations	Reactive	R3, R7, R8, R10
γ_{4}	Stakeholder assigns a certain project statement to project manager within an organization	Reactive	R4, R5, R9
γ_{1}	Designers will design a staffing framework	Reactive	R2

4.3. Solution Generation

In the environment analysis step, we came up with a set of questions (Table 6) as an approach toward analyzing the environment and solving the design problem. We skipped two questions to be answered in the solution generation step. Now we review them:

Q6: What do you mean by "staffing design projects effectively by design teams"?

Q9: How does the framework "effectively staff design projects with design teams."

In the context of solution generation, we can see that the first one (*Q6*) is concerned with defining the requirements for the effective staffing action while the other question (Q9) addresses the method and more details about how the solution works. Thus, in this section, we start by answering the first question, and at the end of the section, we would be able to answer the second question by demonstrating our solution.

4.3.1. Defining Effective Staffing

In a design project, there is a certain goal of accomplishing the project workload within the budget. Accomplishing means to deliver the project within the defined scope (design requirements) according to quality specifications (acceptance criteria for design requirements) which are agreed upon by the project manager and stakeholders. The budget bears different aspects such as time, cost and people.

According to the characteristics of a successful design project, effective staffing would be providing and maintaining a team of people who are capable of coping with the design problem effectively. We should also mention that in this design problem, we are not concerned with team scheduling; however, it is a part of PMBOK practice for human resources management. The reason is that our context is a design project which is commonly complex with interdependent tasks, so having a good performance relies highly on collaboration and we assume team members are available to work together.

The PMBOK processes for project management are widely practiced, and we believe it can be a good framework for supporting our solution. Our solution will provide tools which can support PMBOK human resources management processes effectively in our context of the conceptual design project. According to our analysis in the previous part, we have use cases for the framework that we intend to design. Thus we have basic requirements for designing a staffing framework which a project manager will use as a supporting tool through the project human resources management lifecycle. Additionally, we have the conflicts that we need to resolve.

Hereby, we provide the PMBOK human resources management processes and their definitions tailored to our context of conceptual design projects. Providing such a framework answers *Q6* and provides our definition of this framework. Afterwards, when we answer *Q9,* we will show details of such defined framework.

The Project Management Body of Knowledge (PMBOK), defines human resources management processes as follows [14]:

1. Develop the human resources plan: This process intends to identify project roles, responsibilities and required skills which would be a basis for the staffing management plan
2. Acquire the project team: The process of confirming human resource availability and acquiring the team necessary completing project assignments
3. Develop the project team: The process of improving competencies, team interaction and the overall team environment to enhance the project performance
4. Manage the project team: The process of tracking team members' performances, providing feedbacks, resolving issues and managing changes for optimizing the project performance

According to the presented set of processes, we provide an analogous set of processes for the context of conceptual design projects which follows the same logic. Table 17 demonstrates the definition of this framework. The processes in this framework comply with the lifecycle of the staffing framework that we have provided in the environment analysis section. Referring to the discussion that we provided in the interaction analysis section, we are providing the use cases for our framework in depending interactions. Analogous to the PMBOK processes for managing human resources, we provide a set of processes which support our proposed framework.

Table 17 - Defining the effective staffing framework

Step in the Lifecycle	**Process Objective**	**Use cases in the set of interactions**
S1 – Planning	The process of Analyzing the workload to identify underlying work units and the associated set of knowledge and skills which is required for accomplishing them. The set based on which the staffing management plan can be developed.	I5 - Project manager defines project requirements.

S2 – Acquisition	The process of obtaining an appropriate team from available individuals in the organization regarding their competencies, namely, knowledge and skills.	I6 - Project manager selects from the available pool of individual candidates. I7 - The project manager provides an appropriate team. I9 - Project manager assigns tasks to team members.
S3 – Development	The process of improving and enhancing team members' knowledge and skills for a better performance on the workload	I8 - The project manager maintains the appropriate team. I23 - Project manager develops the team.
S4 – Management	The process of tracking team members' performance to make sure the required resources are available to the team and to resolve raised issues.	I8 - The project manager maintains the appropriate team. I21 - Project manager evaluates design concepts. I22 - Project manager evaluates the team. I24 - Project Manager helps the team to resolve conflicts.

Now that we have formulated our definition of the staffing framework which is capable of effective staffing of a design project with a project team, we can proceed to answer the next question. The answer to "how to" question will demonstrate details of processes which are presented in Table 17 in which the framework is defined.

As we mentioned earlier, conflicts are driving forces of design and resolving conflicts changes the environment to a new environment. Resolving conflicts is a step of EBD in which we generate solutions for changing the current environment toward ideality.

γ_{23}, γ_{24} are critical active conflicts in our Product Environment System (PES) and to come up with an effective solution, we need to make sure that our solution resolves them. In other words, active conflicts exist because there is a lack of action for a needed response which means our solution must be able to provide the missing action for producing that response. This is like providing a solution which meets specific requirements.

4.3.2. How the Framework Works

Following the Environment Based Design (EBD), in this step, we present the conflicts and resolve them in order to come up with the design solution. However, solving reactive conflicts cannot happen in the early phase of design which makes us proceed with analyzing and resolving active conflicts first.

According to our analysis of active conflicts which is presented earlier in this chapter, conflicts regarding interactions I23 and I24 are critical conflicts. These two interactions are concerns of S3 and S4 processes of our defined framework. In other words, there is a lack of action for producing these two interactions in our PES during the project. On the other side, not having active conflicts for S1 and S2 is a sign that in our analyzed PES we have actions which can produce interactions of S1 and S2 concern. We start by resolving above-introduced active conflicts, and we continue by resolving them. Afterwards, we discuss available interactions for making S1 and S2 happen and will propose methods which support our defined framework.

In order to resolve conflicts, we need to decompose the environment into primitives firstly [6]. By primitives, we mean object for which we have the knowledge to evaluate its performance given its basic properties. When we are coping with an active conflict, we should find an object whose performance includes needed responses. Below, we present our two critical active conflicts and demonstrate our effort for resolving it.

γ_{23}: The project manager develops the team (I23), *while* there is no action in PES to trigger this.

γ_{24}: The project manager helps the team to resolve conflicts (I24), *while* there is no action in PES to trigger this.

Both of these conflicts happen during the execution of the project by the team while the project manager monitors and controls the project. Accordingly, we will identify the environment and will decompose the environment into primitives. We use ROM diagram to represent them in Figure 15.

Both interactions happen in an environment where *the project team performs on the workload (I10)*, and before proceeding to provide a solution for developing the team or resolving team conflicts, we need to analyze this environment first.

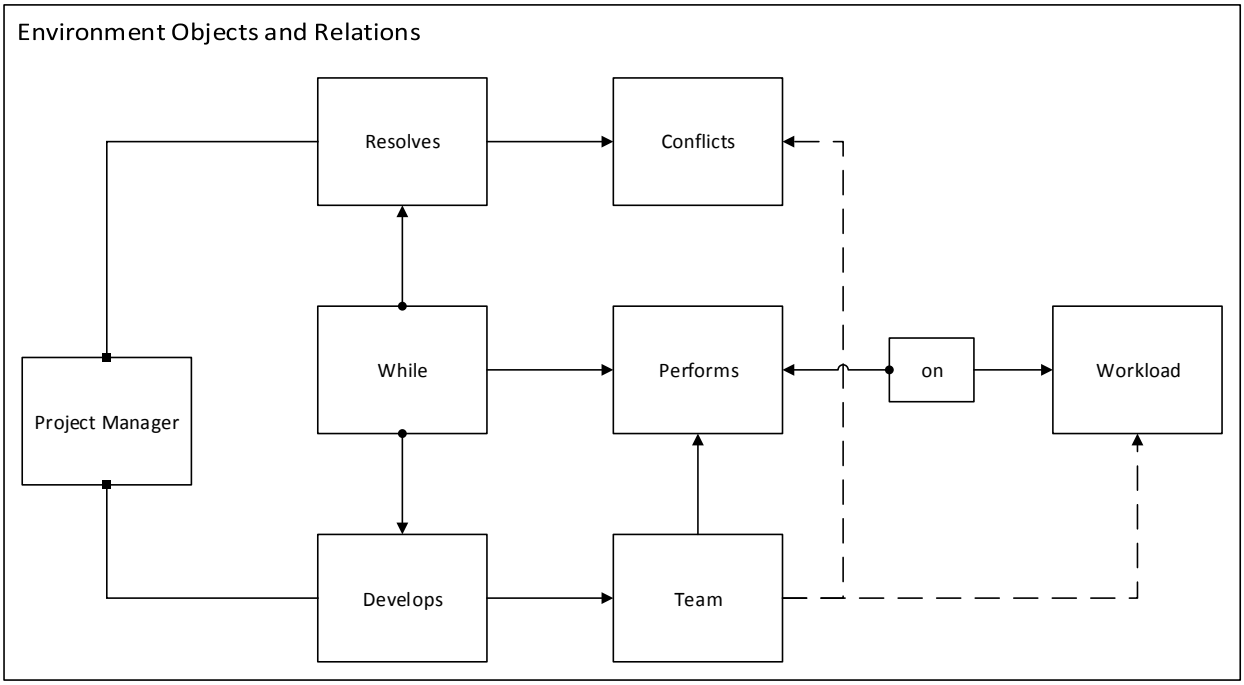


Figure 15 - Environment objects for I23 and I24

As the simplest case, consider one designer who is assigned a simple design task. The designer will perform on this task according to their associated mental capacity [2]. The extent to which a designer can cope with a creative activity such as design activity is related to the mental stress that they perceive. This relation is an inverse U shape.

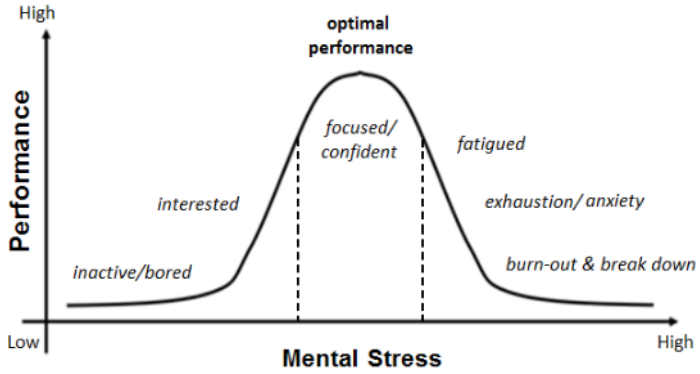


Figure 16 - Relationship between performance on a design task and the designer's mental stress

The mental stress which is perceived by a designer is reliant on the workload itself and the mental capacity of the designer. Facing a design activity, the mental capacity of a designer is defined according to the level

of knowledge and skills that the designer holds relative to the workload. This mental capacity is also affected by some other parameters that are existing in the environment.

Equation 1 – Individual's mental stress relationship with the mental capacity

$$Mental\ Stress = \frac{Workload}{Mental\ Capacity}$$

According to the theoretical model of creativity that we have presented in the theoretical foundation, we know how to evaluate performance for an individual who is dealing with a single design task. The performance depends on the designers' mental stress while the mental stress itself depends on the workload and the designers' mental capacity. In a case where more than one individual is working on a task, instead of availability of individuals' mental capacity we refer to a model of organizational capacity.

As proposed by organizational capability model, the organizational capability is the ability which is demonstrated by a team as a collection of individuals within an organizational context. This capability appears when a project team interacts toward the common goal of accomplishing the project [12]. Organizational capability can be defined as the competency of an organization (project team) to achieve its goals (accomplishing the project) by identifying the right work in a problem solving work (design project) and accomplishing the work. The organizational capability can be presented in a formal way as Equation 2:

Equation 2 – Organizational capability model

$$\begin{aligned} Organizational\ Capability \\ = (Organizational\ Knowledge + Organizational\ Skills) \\ * Organizational\ Affect \end{aligned}$$

Regarding the general creativity model, we have a theoretical model of creativity which we have presented before for describing the design creativity of an individual in a design problem as well as an organizational capability model which is describing the performance in an organization. Figure 17 demonstrates the environment that we are discussing against individual performance on a single task.

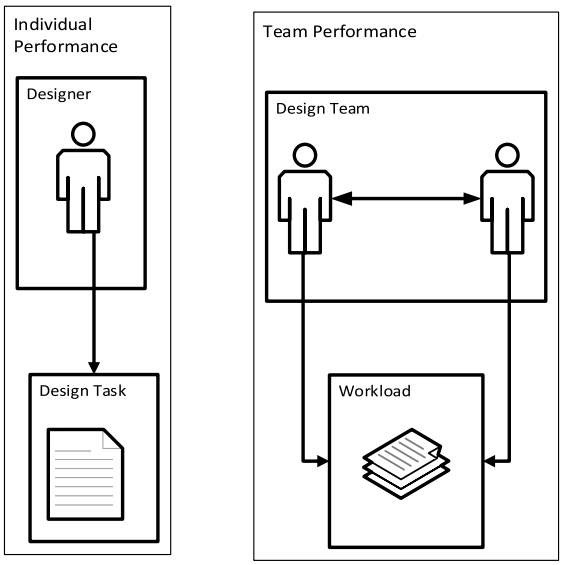


Figure 17 - Demonstration of primitives to the team performance

Table 18 - Comparison of team performance vs. individual performance on a design task

Individual Setting's (Primitive) Environment	**Team Setting's Environment**
Designer	Design Team which is composed of Designers
Design task	Project workload composing of design tasks
Designer performance on the design task	designers collaboratively perform on workload
Designer mental activity	Designers share mental activities

Now, that we have decomposed the environment, we can go back to resolving conflicts which exist in our PES. For this purpose, we take a look back at the definition that we have provided for the effective staffing framework.

4.3.3. Resolving Conflict γ_{23} – Team Development

γ_{23} is resolved if we provide an action to improve and enhance team members' knowledge and skills for a better performance on the workload. Thus, to resolve this, we should focus on enhancing the collaborative performance on the project workload. For this purpose, we provide a training approach based on Project Based Learning (PBL) which can develop certain knowledge and skills in the team.

Commonly, a vast variety of knowledge domains are required to cope with design problems since the design problems are complex problems that require a diverse set of knowledge and skills to be accomplished. Thus, as not everyone knows everything, forming design teams to cope with the design task can bring together

people from different backgrounds to collaborate on the complex design task. The main question is if we have an approach for forming these teams effectively.

As mentioned earlier, effective coping with a workload is reliant on the level of knowledge and skills available to the designer. Thus, following the idea that a design project is composed of some smaller underlying tasks, we can say that for effective coping with a workload the team should be able to cope with composing underlying tasks effectively. In this manner, we can decompose a design project into smaller underlying tasks and staff the design team according to the underlying tasks which can be smaller tasks. This decomposition is analogous to building the Work Breakdown Structure (WBS) in project management. A team that can deal with the underlying tasks of a design task effectively ought to be capable of coping with the original design task.

4.3.3.1. Project Based Learning

Courses are taught for a reason, to accommodate a set of learning objectives. The learning objectives are a set of knowledge, skills and attitudes which can be referred to as cognitive, psychomotor and affective domain competencies respectively according to Bloom's taxonomy [45]. Project-based learning is quite popular in the current education ecosystem as it is capable of challenging students with complex problems similar to real-world problems to equip them with specific competencies. Developing correct competencies can empower students in a way to match better with what the industry looks for in the job market.

In course projects, students integrate knowing and doing to learn knowledge and elements of the core curriculum, while developing their skills by applying them to real problems and producing artifacts [46]. In project-based learning, by transformations and construction of knowledge students obtain new understandings and new skills by coping with the project [47]. Learning outcomes for participants can be categorized into three categories of knowledge, skill-based and affective outcomes [48]. A set of related knowledge, skills, and attitude is called a set of competencies [49]. Working on design projects can facilitate fostering various those competencies in students which are essential for coping with the real-world problems in the industry environment [50], [51].

The participants' cognitive competencies, namely a set of knowledge and skills which are fostered during the project term, are highly dependent on the project problem. Thus, a critical concern arises which should not be overlooked: Is a defined course project fit for its learning objectives? In our study, we attempt to answer this question by evaluating the proposed course project compliance with learning objectives regarding involved cognitive competencies.

4.3.3.2. Tasks and context in a design project

Different kinds of competencies are engaged to be developed during a design project. The first category of those competencies includes the task-specific [52] competencies which are associated with the design problem. This category consists of the technical knowledge and skills which are required to accomplish that specific design problem. The second category includes the competencies which are not associated with the tasks but with the context, that is the project. Delivering a product with specific qualities within a limited time by using available resources results in project accomplishment and is also independent of the design task. Thus for accomplishing the project in this context a set of task-independent [52] competencies is required beside the task-specific competencies. Since design projects are commonly interdisciplinary and complex, they are worked on in a team setting. This context will engage teamwork and interpersonal competencies as well.

When students perform well on a project, it means they have related competencies to some extent. Students can develop specific competencies by accomplishing a specific course project. Specific competencies are fostered in participating students whether they have them before or acquired them through the design session. If a student works on a project in an individual setting, this development can happen either from experience gained from performing project tasks or acquiring knowledge by studying independently from project performance. The complex projects are common to be performed in a group setting. In a team setting sharing knowledge and skills within the team might also be the case which leads to this development. In the team settings not always all team members perform the same task but they may be assigned different tasks based on various principles. Independent from how tasks are distributed and assigned, in the integration and review phase of the project, knowledge and skills are transferred to some extent by interpersonal interactions such as communication and collaboration [21], [53].

A course project can be set up in various ways. So far, we have provided various characteristics for a proposed course project whether in task specifications or context. Based on these characteristics different competencies are involved in the project accomplishment and so learning outcomes. In the next section, we provide a framework for evaluating a proposed course project against the presented criteria.

4.3.3.3. Developing evaluation criteria for course projects

We are interested in evaluating a proposed design problem as a course project assignment for an engineering design course in which participants develop specific competencies. Commonly, design problems are complex, so to evaluate the design problem we need to decompose and analyze this problem. Using a design methodology can be effective for this purpose. We employ the EBD approach toward analyzing the problem

carefully and preparing it for evaluation; this enables us to provide insights for guiding the instructor through reviewing the intended course project assignment with the aforementioned characteristics.

The instructor (who can be the project manager when we are talking about training the design team in a specific project) intends to evaluate whether a defined course project is appropriate for the learning objectives, so he/she should start with an initial project statement. One design project consists of many related tasks toward developing a new product. To find those competencies which are required for accomplishing the project, firstly, project tasks must be clearly defined. All underlying tasks of the project assignment must be completed for its accomplishment. Thus, before going any further, we need to clarify the underlying tasks. A systematic method for eliciting requirements [7] is available in the EBD methodology. This method is based on the environment analysis step of the EBD methodology. The instructor can use this method that is based on a questioning/answering approach, to decompose the project statement into smaller work units.

Availability of relevant resources to perform a job is a part of its requirements for accomplishment. Since we are evaluating a course project, competencies which are required to its accomplishment are analogous to a subset of product requirements. The aforementioned question asking strategy can be employed for systematic analysis of small work units regarding required competencies for accomplishment. Taking this approach for generating questions enables us to systematically review tasks. For answering the question of "how a small work unit can be performed" broad range of available techniques in the literature [54] that are available for cognitive task analysis can be practiced. These skills can answer the question and make it feasible to elicit required competencies as the set of required skills and required knowledge for performing the task.

After understanding the design problem clearly, the instructor must compare the initial problem statement against the learning objectives. This comparison must be made between competencies in the learning objectives set and competencies which are required for accomplishing the project. After this comparison, some modifications are to make the open-ended design problem appropriate for learning objectives. A step by step definition of the framework is presented in the next section to demonstrate the application of EBD approach in this evaluation.

4.3.3.4. The framework for evaluating a course project – An EBD approach

According to the discussion which is presented earlier, the evaluation process for the course project definition starts from an initial problem statement and is followed by a comparison of the statement against the appropriate course project criteria. The outcome of this process is an evaluation of the proposed course

project regarding meeting its learning objectives. In this section, we are providing the steps to be followed for this process as a framework, and we demonstrate it with a graphical presentation afterwards.

As we have mentioned earlier, Recursive Object Modeling (ROM) is used in the Environment Based Design (EBD) methodology for the formal representation of the design problem [5]. This step is before all other steps, so we start analyzing the problem with its ROM representation.

Step 1: ROM representation of the project statement and developing the course's expected outcomes

There are two independent tasks to be done in the first step:

1-1 Formally, present the initial problem statement by using Recursive Object Model (ROM) to model the statement.

1-2 Develop learning objectives for the course regarding competencies that are intended to foster in participating students. In this step, consider different categories of the competencies as discussed earlier. These categories include competencies which are specific to the design problem (task-specific) and competencies which depend on the project context (task-independent) such as the project management or the interpersonal competencies which are essential for accomplishing projects in the team setting.

Step 2: Decomposing project statement into small tasks

Follow the question asking approach which has been introduced. This strategy includes generating questions from ROM diagram by using the specific template. The set of questions consists of generic questions about the design problem based on the generic ROM analysis as well as domain-specific questions [7]. By answering these questions, the design problem is more clarified. The answers must be merged with the initial project statement until no further clarification is required. Underlying tasks for the project accomplishment are identified after enough clarification of the design problem, which can take a few rounds.

Step 3: Specifying the required competencies for performing tasks

Ask how to perform underlying tasks. Start with tasks which are not dependent on other tasks and once they are defined, ask about the tasks that are depending on the defined tasks. Ask questions about methods of conducting identified underlying tasks of the problem. Project workload is decomposed into smaller work units. A set of questions mainly concerned about methods to be practiced for task accomplishment is generated. Different approaches become handy for answering these questions; the formal way can be cognitive task analysis, however, using other techniques for simple tasks might be useful as well. This analysis can also be done by the instructor's experience since the tasks can be detailed enough in the

previous step. Answering those questions specifies the required cognitive competencies such as required knowledge or skill for each work unit.

Step 4: Comparing the required and expected competencies

So far, we have developed two distinct sets of competencies regarding knowledge and skills. Those two sets are competencies which are required for the project accomplishment and competencies that are intended to foster. Now we compare them, so for each competency, the result of this comparison can have a few combinations. Possible combinations of this comparison are presented in Table 19. Make the comparison of all competencies which are available in either of two lists. Roughly speaking, this step is analogous to conflicts identification step in EBD methodology which can be elaborated and followed by the solution generation step in further studies. Following this strategy, instructors acquire insights on how appropriate is their proposed course project to learning objectives.

Table 19 - Possible cases of comparison for each competency

Requisite in the learning objectives	**Requisite for project accomplishment?**	**Project Evaluation result**
Required	Required	Problem complies with learning objectives
Required	Not Required	The problem is limited
Not Required	Required	The problem has inessential workloads
Not Required	Not Required	Problem complies with learning objectives
Non-mandatory	Required	Decision required
Non-mandatory	Not Required	Decision required

This framework enables the instructor to review the proposed course project regarding its suitability to learning objectives. Furthermore, this can provide insight into the opportunities for wise modifications of the course project.

Step 5: Reviewing the proposed problem statement

Design problems are open-ended and can be limited by defining constraints or expanded by defining additional requirements. The evaluation results can be used for modifications of the initial design problem to make it a better fit regarding the learning objectives. The instructor who is designing the course project must make decisions for limiting or expanding the problem definition to aspire to a more appropriate course project. By modifying the design problem according to the presented strategies, the instructor can present a

precise definition of what must be assigned to students and what should be avoided in the project assignment to students.

Hereby, we have provided a framework for evaluating course projects as an assignement to the project team which intends to foster certain competencies in team members. Later in this chapter, we represent details of this module within our framework along with other modules. In the next chapter of this thesis, we will provide a case study accordingly.

4.3.4. Resolving Conflict γ_{24} – Conflict Resolution in a Design Team

Conflict (γ_{24}) is associated with the interaction I24, "the project manager helps the team to resolve conflicts." This conflict (γ_{24}) is resolved if we provide an action to resolve raised issues and conflicts within the design team. This phenomenon does not happen in an individual setting of the design project where an individual designer is working on the workload solely. If we look back at the environment decomposition, we can see that the primary reason for this issue to happen lies within the fact that designers share their mental activity. Thus, the conflicts in a team are rooted in the quality of sharing mental activities as the basic components.

4.3.4.1. Mental Models

We are interested in studying team members' interaction with the workload as well as their peers; we should mention a concept named mental model. Mental models represent reality, and their functionality is to organize the knowledge, explain the behaviour or events and activate the use of knowledge. Individuals describe a system in terms of form and purpose, explain and predict states of the system using mental models [55].

Mental models make the individual capable of interacting with the environment. Individuals and groups use mental models to cope with the complexity of their environment [56]. In a design team, an individual use mental models to interact with their environment including the task and the team. Badke-Schaub proposes five different types of mental models including task, process, team, competence and context [57]. Mathieu 2000 [58] shows that shared team and task-based mental models are both related positively to team process and subsequently the team performance.

Mental models reflect the individual's perception of reality [59]. Thus, the perception of the real workload is crucial to the construction of task mental models. Further, we present a model which describes the perception process for an individual, and then we discuss the qualities of mental models among a design team which are highly reliant on this perception process.

4.3.4.2. Variety in Backgrounds

For a design problem which is complex, design teams are hired instead of individual designers for solving the problem. Design teams consist of individual designers, each bringing their own knowledge, experience, and intuition to navigate the design space and recursively refine both problem and solution until an innovative outcome is reached [60]. Since members of the design team have various backgrounds, most likely each individual in the team perceive the tasks based on his/her experience, professional training and acquired knowledge. The team can only effectively perform if they can find common ground to perform on. Designers collaborate on the workload across the team to manage constraints throughout the design process when they are facing a complex design problem [60].

4.3.4.3. Perception in Design

Once the project manager assigns tasks, designers will work on the workload which they have perceived. As the former research promise, the designer who has a better perception of the design problem will have a better performance on the design task [10]. The perception model in design [10] describes a process of perception by which the real workload is translated to the perceived workload. During this process, one uses knowledge, skills and affect together on a real workload which results in the perceived workload. Knowledge, skills and affects which are used in this process (K^P, S^P, A^P) are a portion of related knowledge skills and affects available at disposal (K^L, S^L, A^L) respectively. This perception process of the workload is depicted in Figure 18**.**

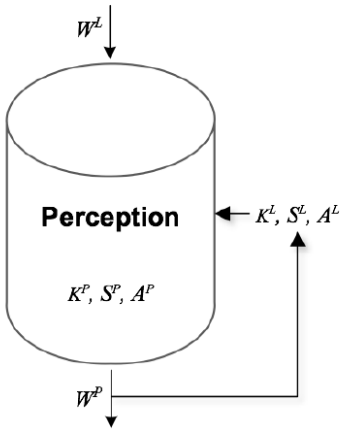


Figure 18 - The perception model for translating the real workload into the perceived workload [10]

Given this perception model, people with different KSA, when dealing with a complex workload which requires a variety of KSA to be accomplished, individuals will perceive workloads differently as a result of

their different mental capacity. According to the theoretical model of design creativity [2] which we have provided in Chapter 2, one's performance is related to his/ her mental stress by an inverse U shape, and the mental stress can be represented by Equation 3 as follows.

Equation 3 - Individual designer's perceived mental stress model

$$Perceived\ Mental\ Stress = \frac{Perceived\ Workload}{(Knowledge\ +\ Skill) * Affect}$$

The denominator in this formula is named mental capacity as we have mentioned before as well. In a design team, members hold different backgrounds and personalities which result in various mental capacities and consequently various perceptions of the workload. Wang [12] presents a model for studying this capability in an organization setting which is called the organizational capability. Earlier, we have formally presented the organizational capability in Equation 2.

We study a design team which is working on a design project in an organizational context while they have the common goal of accomplishing the project. In this manner, our problem is analogous to the organization setting which is studied in organizational capability model [12]. Thus, we can use this organizational capability model to represent the capability of the design team in coping with the design project workload.

4.3.4.4. Perception in a Design Team

The design team in which members have a better perception of the design problem will perform better on the design task. There is an additional point when we are talking about the design team instead of a sole designer. If team members hold a big variance of design problem perceptions among the team, they won't perform well on the design task effectively and efficiently. The reason behind this is that a team is supposed to work toward a common goal or objective which is designing a solution which meets certain declared requirements, but when members hold a big difference in their perceptions, most likely they cannot work toward a common goal. Thus, the level of similarity between the perceptions of individuals in a design team would be an impacting factor on their performance on the design problem [61].

Regarding this discussion, one may assume that more similarity between perceptions among the team can result in better performance in the performance on the design task. This may lead to fewer conflicts within the team, but according to the study [62] conflicts in a team may even have constructive consequences. In fact, the similarity of workload perceptions among team members can help them to collaborate efficiently in a design project context. But we must consider the whole design process to see if the similarity is all that we expect from the team.

In a design problem, it is important to build up a solution space from which the design solution is selected. In a case where the perceptions are very similar, the team cannot be innovative enough. For discussing this, we would like to study this phenomenon within a design problem-solving strategy which comes following.

4.3.4.5. Solving Strategy

In 2002, Stempfle introduced four cognitive operations [63] for dealing with problem spaces. These steps include generation and exploration which are to widen the problem space. Other steps are comparison and selection which are for narrowing the problem space. When there is no shared understanding at the start of a design project, team members need to discuss the issues on hand, and they have to learn from each other. Therefore, the diversity of thoughts at the beginning of a product development project often leads to innovation [64]. While the team is searching for solutions, different views are useful in order to broaden the solution space. A greater divergence of mental models at the beginning of a design task in order to generate creativity, coupled with greater convergence of mental models at the end of the task in order to facilitate implementation, and contributes to high performance. Thus, as an ideal pattern of the design process, the team produces a number of design ideas to develop a comprehensive approach to the problem [61]. This differentiation ought to be reduced while the team interacts, so the team can reach a conclusion. Integration of concepts must occur for such a purpose. There exists an optimal level of mental model sharedness which depends on the task and the stage of design.

Other than similarity and sharedness issues, the accuracy of the workload perception is also important, and this is why better performance is reliant on a better perception. In our context, the accuracy of team members' perceptions of the workload is based on their compliance with the stakeholder's perception of the assigned workload.

4.3.4.6. Team Process

The other type of mental model which is found to have a positive relationship with the team performance is the team mental models which represent one's perception of the team. Better team perception may lead to more effective collaboration on the workload. The knowledge content of this type of mental models contains one's perception of teammates' competencies [65]. In this context, sharedness of the mental model indicate the similarity of team members' perceptions of their peers' competencies including knowledge, skills and affects.

Contents of team mental models have low stability [65] which means that it changes during the project term. According to the Tuckman's team development model [37], it changes over time while the team is working

on the workload collaboratively. This change is a result of collaboration which makes teammates more familiar with each other's competencies as well as peer-learning.

4.3.4.7. Mental stress in a team

As we discussed here, we assume there is a relationship between sharedness of the perceived workload in a team working on a workload and its performance. We expect this relationship to be as depicted in Figure 19 for the solution space exploration phase of the design task and as depicted in Figure 20 for the solution selection phase.

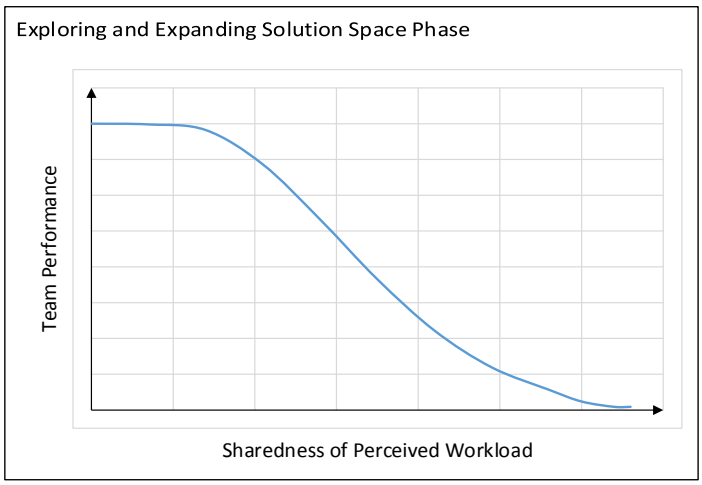


Figure 19 - Relationship between sharedness of perceived workload and the team performance - Exploration phase

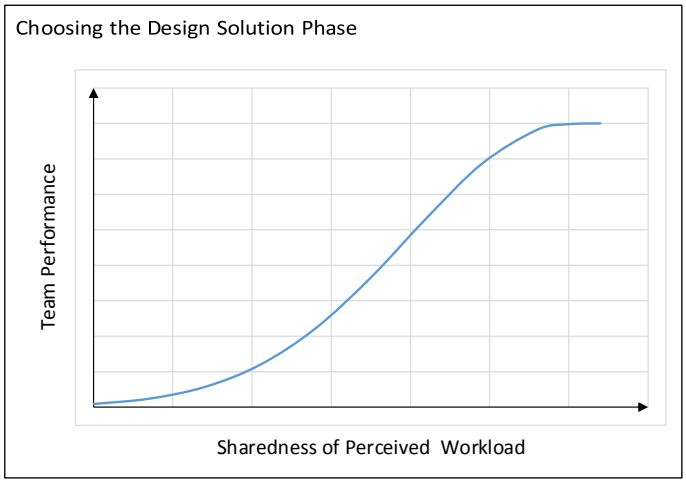


Figure 20 - Relationship between sharedness of perceived workload and the team performance - Solution selection phase

In addition to the relationship between the sharedness levels of perceived workload among the team, we are also interested in the mental stress relationship for an individual in a team. Since each individual has some tasks to be done individually as well as interdependent tasks with different team members, the workload

comes from two sources. We already know the mental stress which is implied by the individual part of the workload, and we propose a relationship for an individual's total mental stress of a project workload in a team project which can be formally presented in Equation 4.

Equation 4 - Individual's mental stress in a team project

$$\begin{aligned} &Individual's\ Mental\ Stress\ in\ a\ Team\ Project \\ &= Mental\ Stress\ of\ Individual\ Tasks\ +\ Mental\ Stress\ of\ Interdependent\ Tasks \\ &= \sum_{Individual\ Tasks} \frac{Perceived\ Workload}{Mental\ Capacity} \\ &+ \sum_{Interdependent\ Tasks} \frac{Percieved\ Shared\ Workload}{Organizational\ Capacity} \end{aligned}$$

Team-based mental models and task-based mental models both are positively related to team performance as a consequence of positive relationships with the team process [58]. Also, they mention that team process fully mediated the relationship between mental model convergence and team effectiveness. These two can remark the importance of the team process for better team performance. According to the corresponding hypothesis' [66], the effectiveness of coping with a problem depends on the extent to which the problem-solving system is compatible with the complexity of that problem. This can indicate the importance of team process and design methodology in a design problem which is commonly complex.

According to the perception model that we have described earlier, we can infer that training which is happening in the team development process, can influence individual's perception and it can also affect the sharedness of perceptions and consequently mental models among the team.

To resolve conflict γ_{24} in this framework design step, we have proposed a descriptive model which can be used by the project manager in different phases to identify conflicts and indicate whether they need to be resolved. The project manager can then manipulate the team design process or perform training in order to resolve the conflict. Developing a prescriptive model the model will need further study to be validated. In our case study which comes in the next chapter, we will observe the divergence and convergence of the team members' perceptions during the design term, and we will discuss it afterwards.

4.4. The Solution - The Proposed Staffing Framework

So far, we have defined the effective staffing framework, and in order to show how it works, we have demonstrated the available interactions in the PES and resolved critical active conflicts by decomposing the environment into primitives and generating solutions based on them. In this section, we are going to present

this proposed framework. This framework is made of four modules that support four human resources management processes which are available in the Project Management Body of Knowledge (PMBOK) accordingly.

4.4.1. 1st module – Workload Analysis

Workload analysis can be done with different purposes such as the development of training terms or developing criteria to certify job competence. This analysis can be used to consider merits for hiring people for specific projects or allocating responsibilities to individuals in a team in such a way which minimizes the required number of persons to be hired for accomplishing the project goal [54].

In our proposed framework, this module is responsible for analyzing a workload once it is defined by a stakeholder. This workload analysis is independent of task performers and emphasizes objectively on the task. This will decompose the task into smaller work units for which the project manager has the knowledge to define prerequisite knowledge and skills for accomplishment. "Workload Analysis" characteristics are as follows:

Objective: To elicit the project's underlying work units and their requisite KSA for accomplishment

Trigger: A new project statement is presented, or a project statement is amended

Input: Initial Project Statement

Output: Work Units and associated sets of KSA

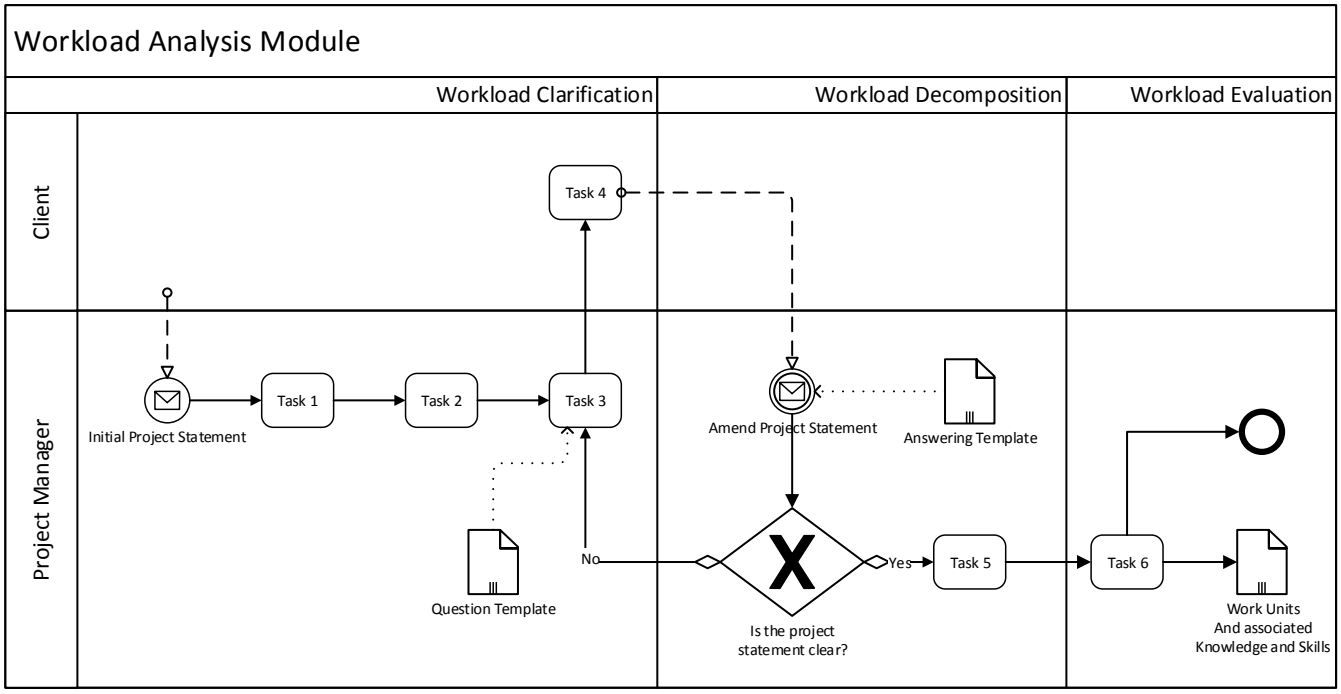


Figure 21 - Main underlying process for workload analysis module

Details for the supporting process of this module is presented in Figure 21 where depicted tasks are described as follow:

Table 20 - Task details for workload analysis module

Item	Description
Task 1	Represent Project Statement by ROM Diagram
Task 2	Generate Question list according to the template
Task 3	Ask questions for clarifying the project statement
Task 4	Answer questions for clarifying the project statement
Task 5	Decompose the project statement into smaller work units
Task 6	Indicate required Knowledge and Skills for accomplishing work units

4.4.2. 2nd module – Team Acquisition

After the workload analysis is completed and the set of required knowledge, skills are available, the project manager can select people from available candidates in the organization. For this purpose, the project manager must indicate the required competency of candidates based on which he/she can decide about team members. The project manager must also be aware of the possibility of training for some certain knowledge

and skills which are required but not available to the candidates in the organization. The project manager ranks candidates according to their impact (potential contribution) on project accomplishment. This ranking should be considered as the project manager's preferences over available candidates. Acquire the team according to restrictions and in a way to have enough resources for accomplishing the project in time.

Case 1: In case there is only one project then acquire sufficient resources for the project team

Case 2: In case there is more than one project then we need to go through a two-sided matching process which we will discuss in discussion and further research in Chapter 6.

Objective: To assess available candidates and acquire the appropriate team for the project respecting available constraints

Trigger: While there is an insufficiency of human resources according to the project staffing plan

Input: Available candidates in the organization, candidates' competency data, available projects, required competencies, preferences data

Output: Project team

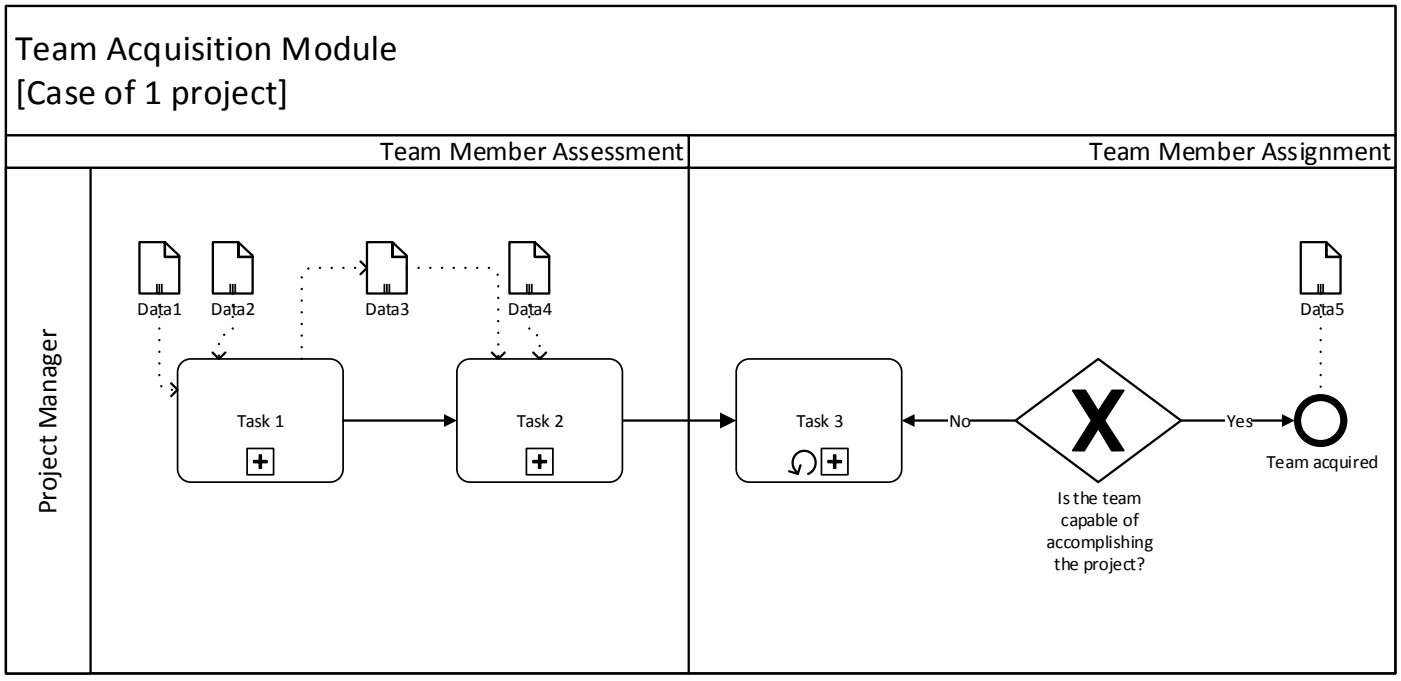


Figure 22 - Main underlying process for team acquisition module

Details for the supporting process of this module is presented in Figure 22 while depicted tasks and data objects are described in Table 21:

Table 21 - Tasks' and data objects' details for team acquisition module

Item	Description
Task 1	Assess Candidate in terms of required Knowledge and Skills
Task 2	Rank Individuals According to their Competencies
Task 3	Hire the most favourable Candidate while there is an insufficiency
Data Object 1	Competency Assessment Method
Data Object 2	List of Required Competencies (set of knowledge and skills)
Data Object 3	Candidate Competency Profile (set of knowledge and skills)
Data Object 4	Work Units And associated Knowledge and Skills
Data Object 5	Team Competency Profile

4.4.3. 3rd module – Team Development

Not always, a project team has access to all the competencies required for accomplishing the project at the beginning. Sometimes, a project manager can opt to develop the team within the organization instead of hiring more people. This can also be considered as an investment in developing the organizational capability which may pay off later. In our proposed framework, the team development module addresses this concern by implementing an EBD based process. This process has a reference to the 1st module as well.

Objective: To make sure that the project team has access to appropriate [cognitive] resources in order to accomplish the project

Trigger: When the required knowledge and skills for accomplishing the task is not available to team members.

Input: Initial Project Statement, Learning Objectives (set of knowledge and skills), Modification Guideline

Output: An appropriate project which is assigned to the project team

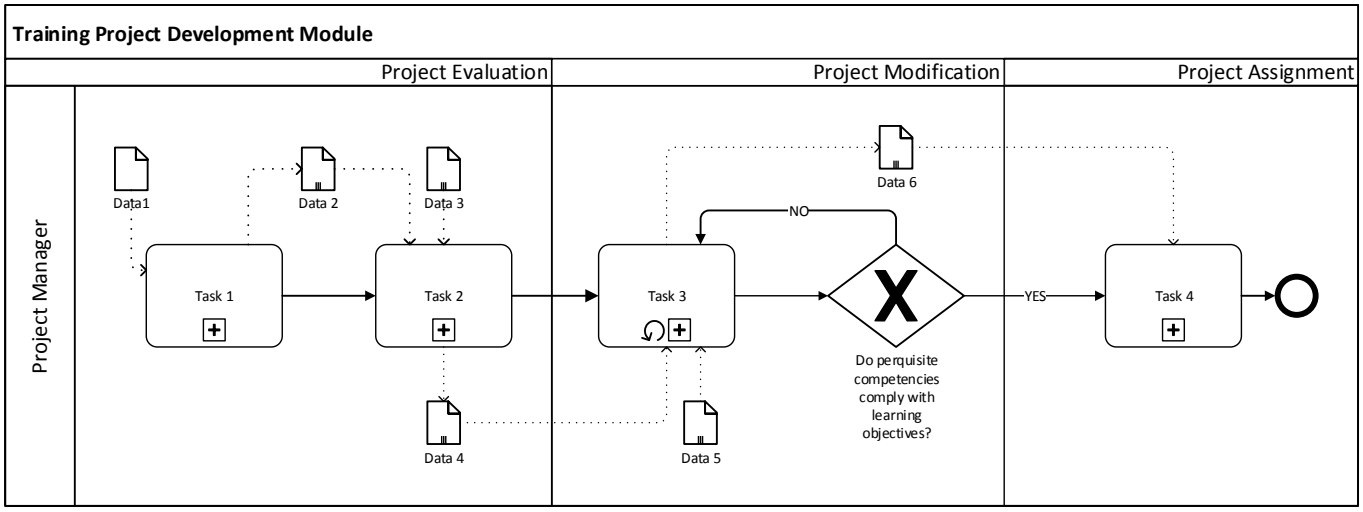


Figure 23 - Main underlying process for training project development module

Details for the supporting process of this module is presented in Figure 23, and Table 22 describes depicted tasks and data objects as follows:

Table 22 - Tasks' and data objects' details for training project development module

Item	Description
Task 1	Workload Analysis for the initial project statement
Task 2	Compare the learning objectives vs prerequisite knowledge and skills
Task 3	Modify Project statement for non-complying work units according to the guideline
Task 4	Assign the updated project statement to the team
Data Object 1	Initial project statement
Data Object 2	Perquisite competencies for the project accomplishment
Data Object 3	Learning objectives (set of competencies)
Data Object 4	Evaluation results
Data Object 5	Modification Guideline (according to Table 19)
Data Object 6	Updated project statement

4.4.4. 4th module – Team Management

In an effort to resolve the active conflict γ 24, we proposed a descriptive model which can be used by the project manager to find out about the conflicts among the team and aspire for resolving them. We have also discussed that effective team training may have an impact on the perception process among the team and so

their mental models. The idea is that the project manager can monitor the sharedness of mental models throughout the project and decide to make interventions during different phases of design.

Objective: To preserve the sharedness of perception of the design problem at an optimal level among team members so they would be able to perform better on the project

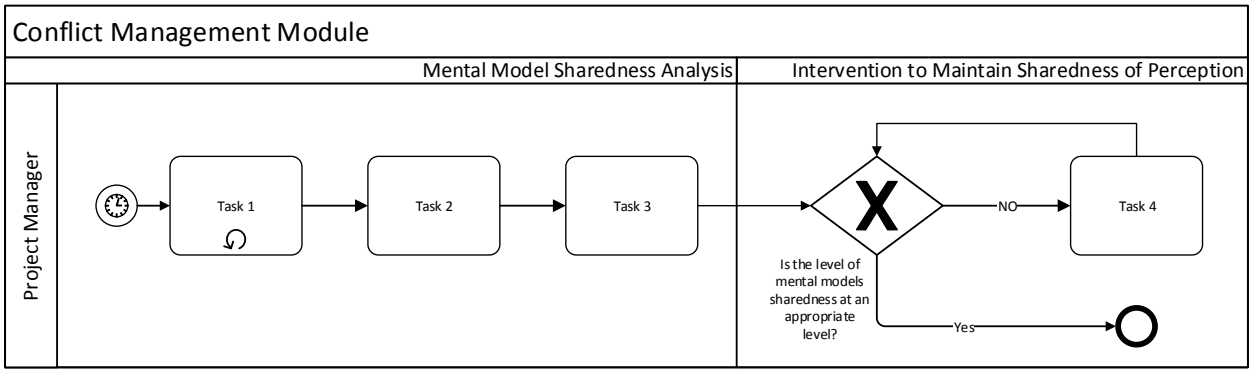


Figure 24 - Main underlying process for the conflict management module

Details for the supporting process of this module is presented in Figure 24, and depicted tasks and data objects are described in Table 23. Interventions which are mentioned in task 4 can be made according to the perception model provided earlier [10] for individuals in compliance with the proposed descriptive model.

Table 23 - Task details for the conflict management module

Item	Description
Task 1	For each Individual, assess mental models (task, team)
Task 2	Assess the sharedness of mental models among the team
Task 3	Evaluate sharedness against optimality according to the descriptive model
Task 4	Make Intervention through the team processes

4.4.5. Solution Summary

Module 1, namely, “workload analysis” module tries to analyze the workload objectively through a well-defined process. This analysis helps the project manager to have a good understanding of the workload, so he/she would be more confident in managing the project. Also, it would be more likely them to assign the project to an appropriate team. This process is started upon the introduction of a new project or in the case of project description amendment.

Module 2, namely “Team Acquisition” module, tries to assign the workload components to a team of available candidates in a way that the team will be most competent in terms of available knowledge and skills within their access. This module is mostly concerning the (K+S) part of the mental capacity formula. According to this process, the project manager can form a project team which has the appropriate capability. Once the team is formed, the project manager can identify that knowledge and skills which the team is lacking for the project accomplishment. Upon identification of required competencies which the team lacks, the project manager must consider alternatives for educating team members and developing the team in those manners.

Module 3, is mostly concerned about the evaluation of the training terms which are planned for developing teams. The underlying processes make sure that the team is developed in a way which is most beneficial to the team objective which is accomplishing the project. This module manipulates the mental capacity among the team since it is developing (K+S) part of the mental capacity formula while the education and team development make the team members more confident resulting in a better “Affect.”

Module 4, is mainly responsible for keeping the teamwork smooth and minimizing the team dynamics. It follows the fact that more sharedness of perceptions among team members [61] results in fewer team dynamics followed by a better “Affect” among team members when coping with the project. The underlying processes are concerned about assessing the perceptions among team members and comparing them to do interventions if needed according to the team perception model.

In the next chapter, we are going to introduce a case study in which we have applied the above-mentioned module to staff a team and support them toward accomplishing the assigned project. The promising result of their performance on the design problem can be affirmative evidence for the effectiveness of this proposed model.

Chapter 5

The Case Study

5.1. Case Study Introduction

In the "Concordia Design Lab," we defined a conceptual design project and applied the proposed framework for staffing the project and managing the team through the project up to its accomplishment. In this chapter, we demonstrate the application of the proposed framework in this specific project and share our observations and inferences.

According to the proposed framework, we present four sections in this chapter including task analysis, team acquisition, team development and team management.

5.2. Task Analysis

The initial design statement is as follows:

"Design a house that can easily fly from one location to another location."

The result of this experiment was expected to be a conceptual design which can meet the aforementioned statement. According to the proposed framework, as the first step, we are going to analyze the task in order to find out the required knowledge and skills for accomplishing this project. In this section, some material from "Environment-Based Design" book is used [6].

We begin by drawing the ROM diagram for this statement, and we will analyze the task based on the diagram. This diagram is depicted in Figure 25.

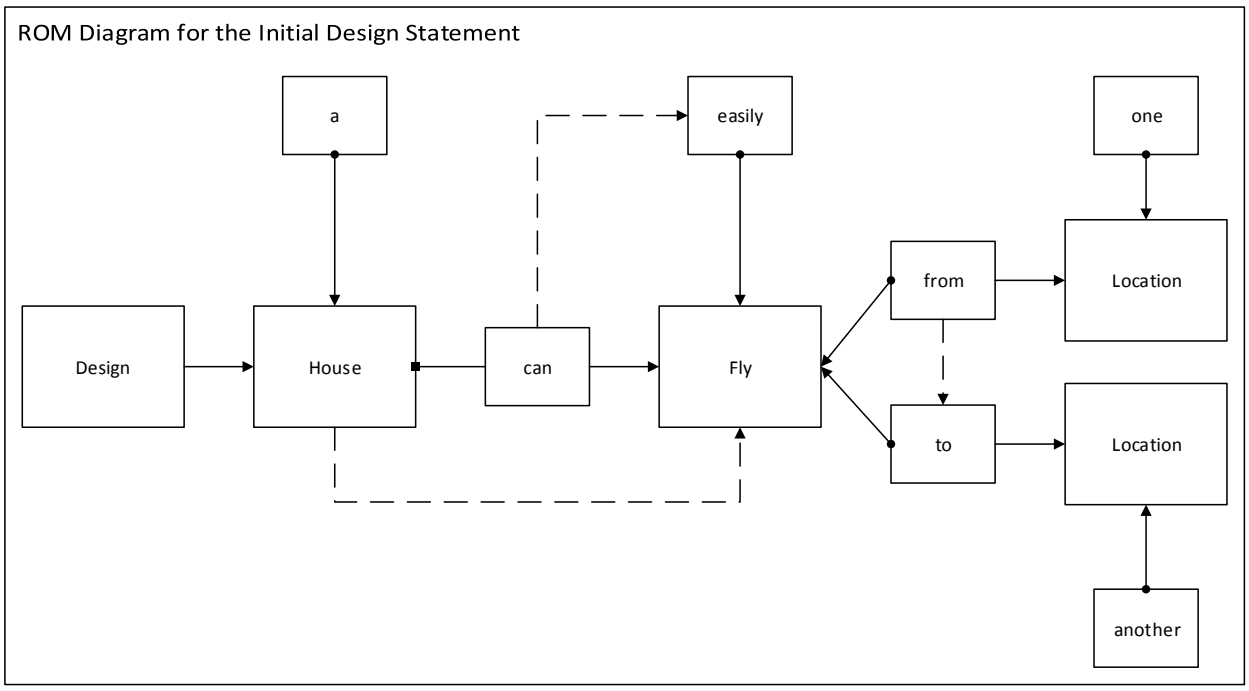


Figure 25 - ROM Diagram for the initial design statement of the case study

Now, we start asking a series of questions and answering them. We do questioning and answering until we can put the design statement in clusters for which we are able to determine appropriate competencies for accomplishment. We start asking questions according to the rules that we have introduced earlier for analyzing ROM diagrams. Questions which are generated based on this diagram are listed in Table 24.

Table 24 - Right questions generated based on ROM diagram along with right answers

#	Question	Answer
Q1	What is one location? What is another location?	[G1/C] There are three kinds of locations. Starting location, intermediate and the destination. When flying, the intermediate location is the air. The start and the destination can be different kinds of surfaces such as beaches, lakes, forests and mountains.
Q2	What is a house?	[G1/A] A house is where people do daily activities. The lifecycle of the house is design, manufacturing service, maintenance and recycling. Design stage: the natural environment is ignored. The human environment is designers; the built environment is technical resources and design tools.

		For the event of transportation, the natural environment is earth, air, or any natural location in which a house will stay as well as animals and birds in the environment. The built environment includes vehicles along the way, all of the build places in which the house may stay. The human environment includes house inhabitants and other people who may interact with the house. For the event of daily activities, we must consider environment components for accommodating daily activities such as the ones mentioned earlier.
Q3	Why design a house?	[G5] To provide a place for people to stay and do everyday activities.
Q4	What does fly mean? What do you mean by fly easily?	[G6/B] This question should be skipped for the solution generation, so we skip it for now.
Q5	When does the house fly from one location to another location?	[G3/B] The house flies whenever people intend to.
Q6	Why does the house fly from one location to another location?	[G5] To transport people easily from one location to another location
Q7	Who will fly the house?	[G2] People fly the house.

By answering questions, we gather more information on the design problem which updates the design statement. We have the updated design statement followed:

"Designers will design a house that can fly easily from one location to another location including air, home, beaches, lakes, forests, mountains, and cities. The house will transport people, who will fly the house when they want. The house will interact with people, animals, and vehicles when it flies. While they stay in the house, people do activities including dining, cooking, cleaning, relaxing, sleeping and entertaining. During the conceptual design of the house, the designer will use design tools and technical resources."

We cluster the underlying tasks for the project accomplishment as seen below:

1. Designers use design tools and technical resources to design the house.

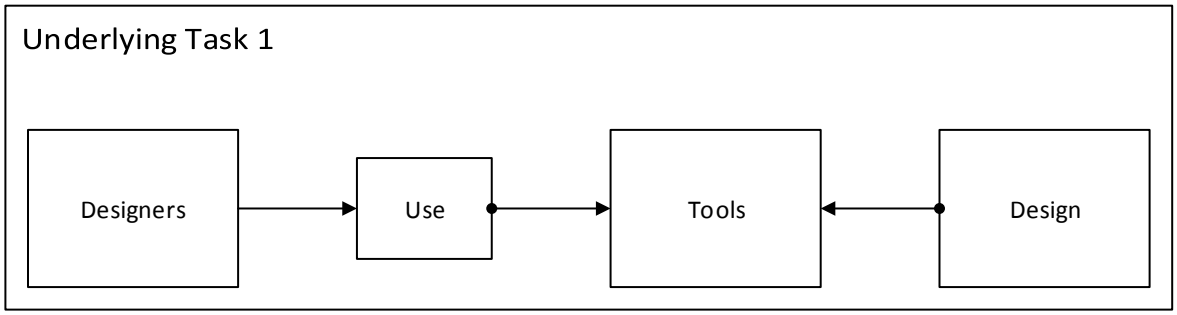


Figure 26 - ROM diagram for design project underlying task 1

2. While people stay in the house, people do activities including dining, cooking, cleaning, relaxing, sleeping and entertaining. People may leave the house.

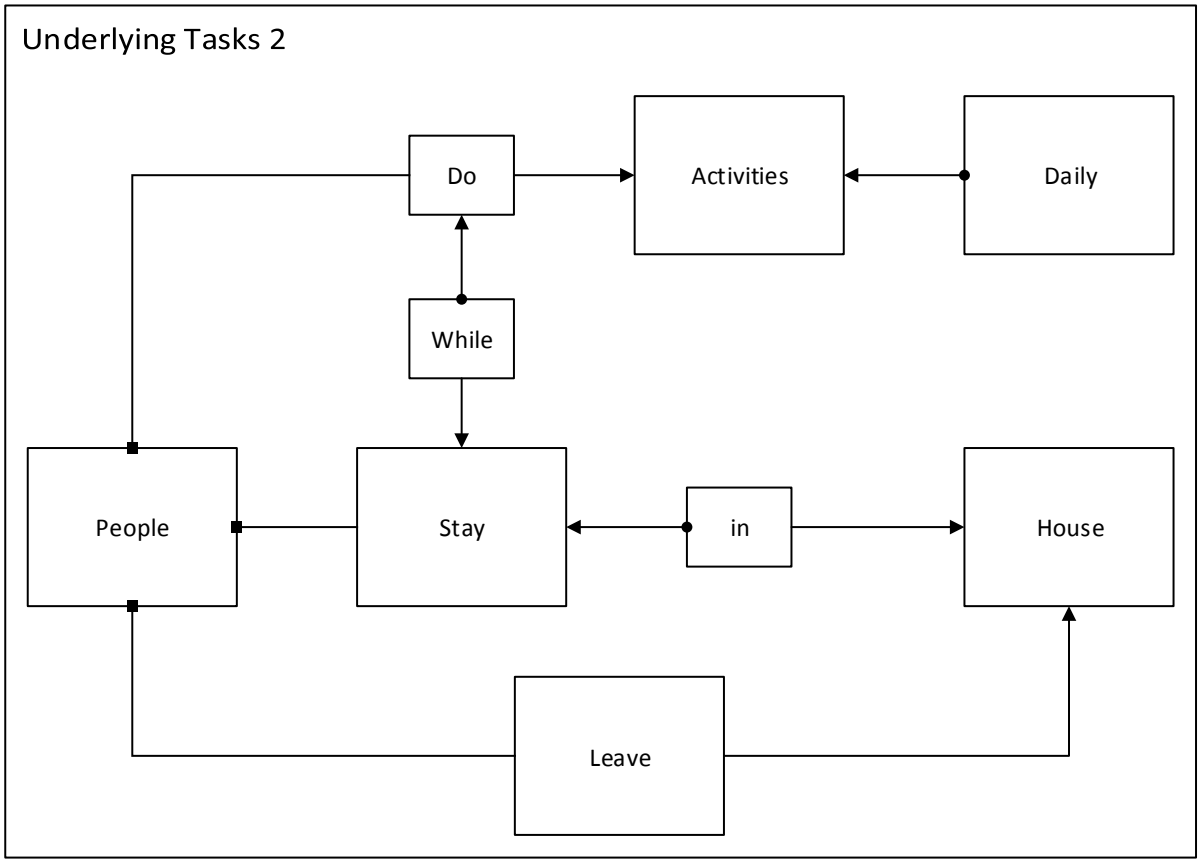


Figure 27 - ROM diagram for design project underlying task

3. House can fly easily from one location to another location including air, home, beaches, lakes, forests, mountains, and cities. The house will transport people, who will fly the house when they want to leave the current location and stay in another location.

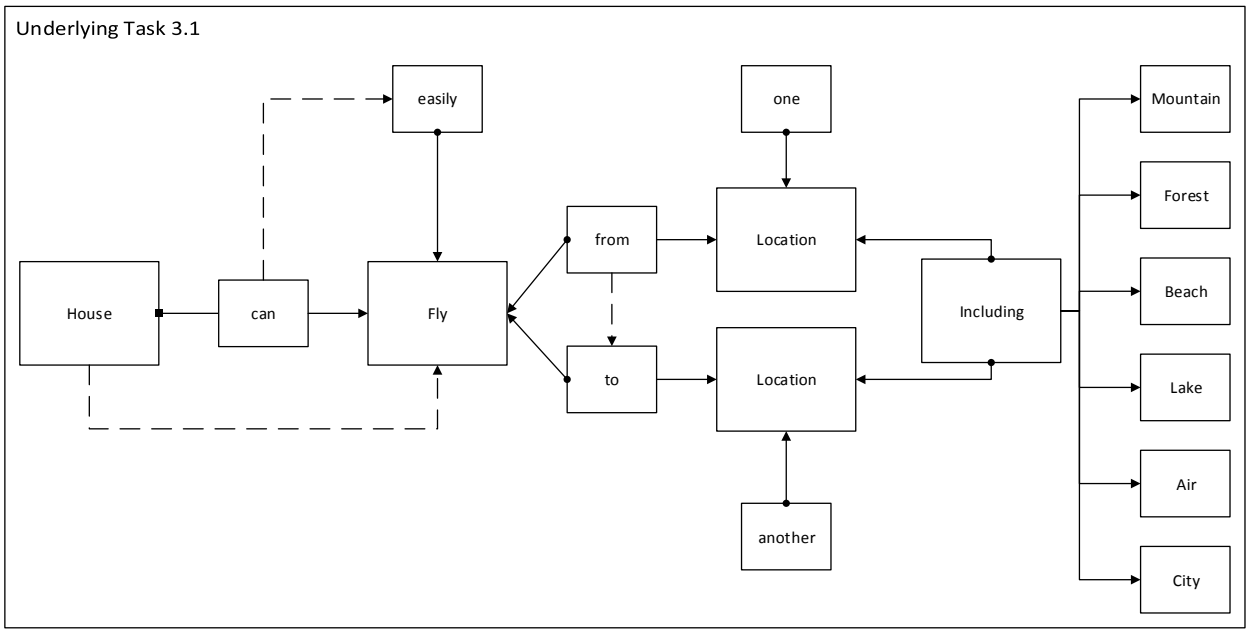


Figure 28 - ROM diagram for design project underlying task 3.1

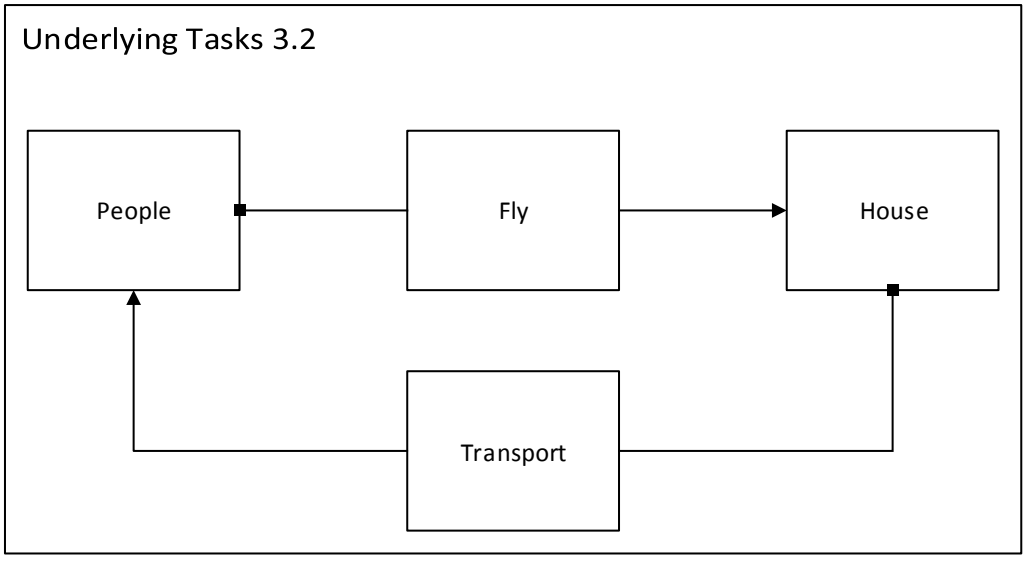


Figure 29 - ROM diagram for design project underlying task 3.2

4. The house will interact with people, animals, and vehicles when it flies

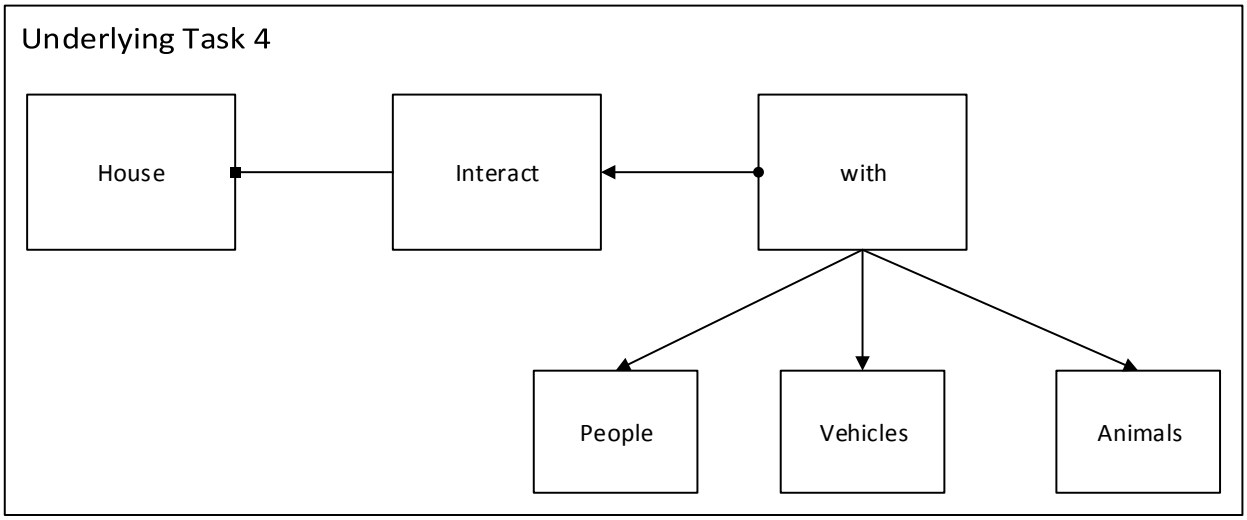


Figure 30 - ROM diagram for design project underlying task 4

This questioning and answering process can be continued until the project manager can indicate the required knowledge and skills for the project's underlying tasks. In our case study, one iteration of initial satement decomposition is sufficient, and we can judge about requisite competencies. Hence, we stop doing further questioning/answering. According to the underlying tasks elicited from the initial design statement, the required competencies for accomplishing the project are listed in Table 25.

Table 25 - Required competencies for accomplishing the design project

Task	**Function**	**Prerequisite Skills, Knowledge**
Underlying Task 1	Use Design Tools	Design Methodology, Design Thinking
Underlying Task 2	Accommodate people' daily activities in the house	Architecture, Interior Architecture
Underlying Task 3.1	House Flies	Mechanics, Aeronautics
Underlying Task 3.2	People Fly House	Control , User Experience
Underlying Task 4	House interacts with objects	Safety

5.3. Team Acquisition

According to identified underlying tasks and indicated perquisites for accomplishing them, we develop a staffing plan for this project, and we must acquire the project team. In this study, we had one project in our organizational context whereas commonly in project-based organizations there would be more parallel projects and the organization staff may be involved in more than one project at a time. In these cases for acquiring the team, more parameters can be considered, and there would be strategies to staff teams to acquire teams appropriately. We will discuss the case of more than one project and a two-sided matching approach for its solution in the discussion which comes in the next chapter.

It is worth mentioning that in the case of a conceptual design project, we are mostly concerned with developing appropriate concepts which are capable of accommodating design requirements. Thus, estimation of the required effort for optimizing the number of team members and associated scheduling which are well-developed with widely-used techniques in routine projects are not the focus of this study.

In our study, we interviewed a few people, mostly students of Concordia University at the time, and we chose some of them according to their match with the prerequisite knowledge and skills for the project accomplishment and their interest in the project. Communicating the project statement which comes follow, the design project started. This statement indicates three cohorts of people with interdepended tasks and the common goal of the flying house design that was mentioned in the previous section. The information disclosed in this communication is demonstrated below:

Design Problem Statement

Design Problem: Design a house that can easily fly from one location to another

Design Deliverable: Deliver three design concepts in forms of design log and sketch by using different principles.

Task Assignments: After analyzing the initial statement, the project manager divided the task into three subtasks as indicated in Table 26. Teams begin to work on their assigned subtasks, and they will be merged into a larger team to integrate their designs later. These assignments are presented in Table 26.

Table 26 - Tasks assigned to cohorts of participants in the case study

Task	Participate	Email
Design a house that can accommodate people's daily activities	Subject 1	Disclosed to team

	Subject 2	Disclosed to team
Design the part that makes the house fly from one location to another location	Subject 3 Subject 4	Disclosed to team Disclosed to team
Design the part that helps the house interacts with the environment	Subject 5 Subject 6	Disclosed to team Disclosed to team

We should mention that the name and contact information of team members are disclosed to all of the team at their consent. However, we will not disclose the names and identities of the subjects who consented to participate in our experiment. The consent form which is signed by participants can be found in Appendix C – Consent Form.

We describe a profile of the selected team members for the purpose of demonstrating team acquisition step in our framework which is applied in this project. Table 27 demonstrates team members' profiles. All of our subjects except subject 4 were graduate students at Concordia University throughout the project.

Table 27 - Case study participants' profiles

Subject	Background
Subject 1	Educated in architecture engineering major with professional experience in the same field. Architecture
Subject 2	Educated in building engineering major.
Subject 3	Educated in aerospace engineering with professional experience
Subject 4	Educated in mechanical engineering with professional experience
Subject 5	Educated in Electrical and computer engineering
Subject 6	Educated in Electrical and computer engineering

Regarding the team profile and prerequisite knowledge and skills for project accomplishment, the team is appropriate for accomplishing the conceptual design project. We also asked team members for self-evaluating themselves in domains which they consider crucial for the accomplishment of the project. We will demonstrate the application of other framework modules in the next sections of this chapter.

5.4. Team Development

In this section, we discuss the capabilities of the flying house design project as a project to be used for a project-based learning assignment. This ought to be accounted for as a case study for the team development module of our framework. Then, in section 5.4.2 we discuss how it can be applied to help the project team that we acquired for improving the competencies which they may lack.

5.4.1. Demonstrating Team Development Module, a Case Study

As we discussed in the team development module in the previous chapter, the first step would be analyzing the initial project statement for the course project which is to be assigned to the team or members. We have done this step in the "Task Analysis" section of this chapter. Once the task analysis step is done, we have the result of "task 1" in the second module. Before proceeding with the design project case study, we first show how the project workload can be modified in order to involve various competencies. This demonstration stands as a case study of "module 3" of the proposed framework. Afterwards, we continue the design project case study for validating the proposed framework and show the case of a training session as an application of the "module 3" of the framework, namely, team development module.

In this case study, we are demonstrating the process, and we are not scrutinizing tasks despite its feasibility. The process of task analysis must be stopped at a level where the analysis and decision making is possible for the instructor that can also depend on the instructor's experience.

The underlying tasks of the project can be extracted from the clarified statement of the problem. These tasks and their relative set of knowledge and skills that are required for accomplishing them are presented in Table 25. We illustrate a more detailed analysis of the required knowledge and skills to show how the modification of the project can be designed and performed. As we mentioned before, the task analysis can be done at different levels for different purposes. For the purpose of team acquisition, we deepened our analysis to a level by which we can decide about people who are needed to be acquired for a successful team. For this step, we may need a deeper analysis of the task and required competencies for effective project evaluation in the context of project-based learning, by which we can judge about the project modifications. Table 28 provides more details on the required knowledge and skills for accomplishing the tasks:

Table 28 - Required knowledge and skills for accomplishing project tasks

Task	**Sub-Task**	**Required Competencies (set of knowledge and skills)**
House Flies	The house can move	• Mechanical engineering principles • Kinematics principles

		• Dynamics principles
	The house moves under people's control	• Ergonomics • Electronics and computers engineering
	The building can move between air, sea, land	• Aerodynamics engineering including aeronautics and Astronautics • Naval mechanics engineering principles • Auto mechanics engineering principles

For the purpose of demonstration, we show how the involved set of knowledge and skills can be affected by limiting the environment. Regarding "module 3" of our proposed framework, as the "Task 2", now we should compare requisite competencies against learning objectives. As mentioned earlier, developing learning objectives is not within the scope of this study, but based on a presumed set of learning objectives, as the evaluation criteria, Table 29 can demonstrate a possible set of results which we will discuss.

Table 29 - Evaluating proposed course project against its learning objectives

#	Competency (Knowledge, Skill)	Requisite in the set of learning objectives	Requisite for the project accomplishment	Project Evaluation result
1	Architectural design	Required	Required	Problem complies with learning objectives
2	Telecommunication engineering	Required	Not Required	Problem is limited
3	Naval mechanics	Optional	Required	Decision required
4	Astronautics engineering	Not Required	Required	The problem has inessential workloads

As the next step, we ought to modify the project statement to accommodate learning objectives by resolving non-compliance learning objectives.

For row #1, no modification is suggested since the competencies are required in both sets and the project workload is complying with learning objectives.

For the row #2, knowledge and skills of the telecommunication engineering must be involved in the course project as of instructor expectations whereas it is not necessary for accomplishing the proposed project statement. This insight enables the instructor to expand the problem statement wisely. The following

requirement is suggested to be added to the design problem: "The house must be able to communicate with control towers on the ground."

For comparison row #3 a decision must be made in which the instructor decides about the learning objectives. The instructor decides to avoid naval mechanic engineering as a learning objective, so the evaluation result is as row #3'.

#	Competency (Knowledge, Skill)	Requisite in the set of learning objectives	Requisite for the project accomplishment	Project Evaluation result
3'	Naval Mechanic engineering	Not Required	Required	The problem has inessential workloads

For row #3' and #5 problem includes inessential workloads. We can consider constraining problem for a more appropriate course project. For this reason, we must remove underlying tasks which require specific competencies in #3' and #4. The following constraint is an effective example in dealing with this case: "The house must fly only between lands on the earth's surface."

This review helped us to modify the proposed course project in a way which makes it more appropriate for the course learning objectives. These modifications can be proposed wisely and according to the instructor's experience in the presence of the insights from the evaluation. By employing the proposed framework in this case study, we demonstrated its effectiveness in the evaluation of the initial course project and providing insights for its improvement toward a more appropriate course project. The updated problem statement is presented below:

"Design a house in which one family lives. The house is a building that can move through the air under control from an area on the earth's surface to another area on the earth's surface. The building must communicate with control towers on the ground."

5.4.2. Applying the Team Development Module in Our Case Study

In comparison between the team profile and required competencies for accomplishing the project, given the self-evaluation results from subjects, we find out that most designers are unfamiliar with design methodologies which we indicated in Table 25 as a requisite for accomplishing the project. For overcoming this issue, we decided to teach them about a design methodology, so they would have required competencies for the conceptual design project.

In a session during the experiment term, we taught Environment Based Design (EBD) to the team, and we asked them to accomplish the project using this methodology. This methodology is taught to them by Dr. Zeng, who is the expert in this subject.

5.5. Team Management

The task mental model relates to a person's stored knowledge regarding a particular task. From a design perspective, the knowledge about technology is not different in essence from other knowledge related to a task. Therefore we treat knowledge about the equipment as part of the task model. It also includes product knowledge, such as relevant information of the object to be designed. Additionally, we propose a process model that refers to the knowledge of how to solve a design task. These can be problem-solving strategies as well as particular design methods that are used by designers when performing a task. The process model is different from the task model as it focuses on how to handle a task and not which knowledge of facts is needed when performing a task." [57]

To assess contents of the mental models among the team, we attributed task mental models based on tasks which are assigned to teams at the kick-off. Additionally, we consider the problem-solving process since task mental model contents include the knowledge about the product as well as the solving process [57].

We asked subjects to describe the design task outcome at the beginning of the experiment and at the end. These data are presented in Table 30 and Table 31 respectively.

Table 30 - How subjects have described the design task at the beginning of the study

START	S1	S2	S3	S4	S5	S6	Times Mentioned
Solving Strategy	0	0	1	0	0	0	1
Accommodating people daily activity	0	0	0	0	0	0	0
House Flies	0	0	0	0	0	1	1
Control and Safety	0	0	1	0	0	0	1
Deliverable (Integrated Solution)	1	1	1	1	0	0	4
Number of aspects mentioned	1	1	3	1	0	1	-

In this analysis, to assess the similarity of problem solving approaches among team members, we have indicated whether they considered anything about each aspect or not. In the beginning, only one subject indicated more than one aspect and the only subtask which is shared to some extent is the deliverable type while they neither mentioned much about the details of the product nor its functions.

Table 31 - How subjects have described the design task at the end of the study

END	S1	S2	S3	S4	S5	Times mentioned
Solving Strategy	0	1	1	1	0	3
Accommodating people daily activity	1	0	0	0	1	2
House Flies	1	0	1	1	1	4
Control and Safety	1	0	1	1	1	4
Deliverable (Integrated Solution)	0	0	1	1	0	2
Number of aspects mentioned	3	1	4	4	3	-

This comparison can show how subjects started to tackle the problem from different perspectives and after using a certain design methodology and effective communication they ended up sharing their mental models to a greater extent. All of them mentioned more aspects than their initial answers.

The special case of subject 2 is that he mentioned that the answer is not clear for him and he needs further clarifications while Subject 6 was not available at the final session. However, she has contributed to the final design solution.

One other perspective that has indicated by some subjects is the energy which is required for the flying purpose and enough supply of energy for living purposes.

For all of the aspects except deliverable (integrated solution), more subjects mentioned them. Deliverable aspect seems less of a concern to the team members for two reasons. Firstly, they have learned EBD and implemented the methodology in which the focus is on the environment rather than the solution and the other reason may be the stage in which they were at the end of the design, so they had decided about the form of their deliverable and they shared perception on this to a great extent.

In summary, subjects held relatively more comprehensive and further shared perceptions in the final stage of design. This fact demonstrates the converging process of task mental models among the team.

	Beginning	End
Solving Strategy	■	■ ■ ■
Accommodating people daily activity		■ ■
House Flies	■	■ ■ ■ ■
Control and Safety	■	■ ■ ■ ■
Deliverable (Integrated Solution)	■ ■ ■ ■	■ ■

We are assessing mental models to resolve conflicts, and as discussed a team can work better on a conflict where they perceive it more similar. We investigate how similar do they perceive the most important conflict within the team during their design process. We asked subjects to mention the most important conflict that they have observed during the design process. Table 32 presents how team members answered this question.

Table 32 - Most crucial conflict throughout the design observed by subjects

S1	The system which should be considered for flying purposes
S2	From an architectural point of view cube-shaped design would be the best choices, as there would be more space. But from the aerospace point of view, the flying house must have an aerodynamic shape to reduce drag to its minimum. It must be solved based on expectation of the customer
S3	The most important conflict lies in the shape of the house. In order to solve it, we have decided to put all the control units inside the flying house. But the lights could not be moved inside, so we just try to make them as small and as flat as possible. Our team had a certain preferred material which may differ from the choice of other groups. In this case, we worked together finding a compromise.
S4	The most important conflict is where we can put something outside the house to prevent bird attack. At beginning we plan to put some light bulbs and ultrasound devices outside the house, however, after the discussion with other group members, we decided not to use light bulbs in the flying house and put the ultrasonic devices in the house. This means we have to choose a proper frequency so that it's not harmful for the agent of the flying house.
S5	the shape: something between cubic and airfoil shape --> which could be sphere (the solution) || stability of the house for occupants during flight: using spring shape links between house body and engine plate

As a result, all subjects mentioned issues for the flying function of the house and three out of five had mentioned the exact same issue with the shape of the house in which there has been a conflict between architectural and aerodynamic requirements.

In this section, we demonstrated how EBD could be effective in managing the design team perception and conflict resolution. Further studies can use a similar methodology to obtain more data for some statistical analysis. In our case, team members were not familiar with EBD, and we trained them on this subject while different control group methods can be used for doing research with different purposes. To demonstrate how successful the design project was we should evaluate the final solution which is presented in the next section.

5.6. Validating Final Design Solution

Table 33 presents the set of criteria for evaluating the design solution which is based on the expert's solution to this problem which is a result of following EBD process for the initial design statement which is provided earlier in this chapter.

Table 33 - Criteria for evaluating design project solutions

• Accommodate people's daily activities in the house	1. Consider the required space 2. Providing some details 3. Required Energy
• House Structure	4. Structurral Components 5. Structure Analysis
• House Flies	6. Flying Mechanism and Capacity 7. Force Analysis (Considering gravity and air resistance) 8. Weather Conditions 9. The temperature profile of the air 10. Define Locations
• People fly the house	11. Operator 12. Passengers 13. Control Equipment 14. Emergency Conditions
• House interacts with objects	15. Places for landing and take-off 16. Considering Flying Objects 17. Safety Equipment
• Solution Presentations	18. Make Assumption(s)

	19. Write Decision-making processes 20. Justification of the design 21. Sketches
• Considering Lifecycle	22. Taxi 23. Take-off 24. Cruise 25. Landing 26. Emergency

Now, we are interested in measuring the extent to which requirements are satisfied by the presented solution. We use a performance rate measure as follow which is used by [67] and is appropriate for this problem.

To evaluate if a requirement is satisfied or not, a three-scale value system is used: 1 for satisfied, 0.5 for likely to satisfy, and 0 for not satisfied, denoted by t. The Performance rate can be calculated by Equation 5:

Equation 5 - Rate of performance formula

$$RP = \sum_{j=1}^{m} \frac{t_j}{m}$$

Where, t_j represents the satisfactory score for the j^{th} requirement in the design solution; and m denotes the number of requirements to be satisfied.

Criterion	Comment	Scale
1	Considered residential area, Considered Mechanical, Electrical and Plumbing systems (MEP)	1
2	Indicating residential areas and MEP locations in the solution, Flexible plans based on clients' need, Staircases	1
3	Considered solar panels	0.5
4	Main Core, Main Structure, Discussing Building Envelope qualities	1
5	Discussing material for the shape and skeleton of the house	0.5
6	Considered rotor engines for vertical and horizontal movements	1
7	Discussing the shape of the house from architectural and aerodynamics perspectives	0.5
8	Considered double facade building envelope for energy saving, Considered solar and wind energy production, Protection from UV, Not considering if a certain weather	0.5

	condition is not available or when it causes conflicts in the system, for example, a thunder	
9	Not considered	0
10	Air, Flat surface, Mountain, Sea are defined as locations	1
11	People are depicted in the solution but they nothing is mentioned about their control over the system	0
12	People are depicted in the solution, Some safety concerns are discussed like UV protection	0.5
13	Control room and supporting system is indicated in the building	1
14	Emergency conditions are not considered, only some warning lightings are considered in the design	0.5
15	Solutions for landing and take-off mechanisms in different places like mountains are provided	1
16	Lightening systems and protection devices are considered in the design as well as safety equipment which makes birds avoid nearing the house when it flies	1
17	Safety equipment is considered for the house, Some basic equipment like seatbelts are not considered though	0.5
18	The solution is provided based on assumptions	1
19	They have provided decision-making processes for critical concerns	0.5
20	They have tried to justify their design by connecting requirements, drawings and annotations	1
21	They provided sketches for designed concepts	1
22	The solution considers motors for flying vertically based on which taxi is not needed.	1
23	Considered	1
24	Not considered explicitly but it is well discussed	0.5
25	Considered	1
26	Not considered	0

$$PR = (1 + 1 + 0.5 + 1 + 0.5 + 1 + 0.5 + 0.5 + 0 + 1 + 0 + 0.5 + 1 + 0.5 + 1 + 1 + 0.5 + 1 + 0.5 + 1 + 1 + 1 + 1 + 0.5 + 1 + 0)/26 = 0.711$$

Accommodate people's daily activities in the house	$\frac{1 + 1 + 0.5}{3} = 0.83$

House structure	$\frac{1+0.5}{2}=0.75$
House flies	$\frac{1+0.5+0.5+0+1}{5}=0.6$
People fly the house	$\frac{0+0.5+1+0.5}{4}=0.5$
House interacts with objects	$\frac{1+1+0.5}{3}=0.83$
Solution presentations	$\frac{1+0.5+1+1}{4}=0.875$
Considering lifecycle	$\frac{1+1+0.5+1+0}{5}=0.7$

Chapter 6

Conclusion and Future Research

6.1. Conclusion

In this thesis, the team design problem is tackled as a design problem. Intuitively, for solving a design problem, we have employed a design methodology, namely, Environment-Based Design (EBD). This research tries to demonstrate the effectiveness of EBD in solving such a design problem. Following the EBD methodology, we came up with a framework as the solution which is capable of supporting human resources management processes in a conceptual design project. This framework proposes some tools for supporting the task analysis to be used for developing the project staffing plan. Consequently, it proposes a basic process for staffing the project team which can be further developed as we discuss in the discussion section. This framework also provides supporting tools during the project in terms of providing training and resolving conflicts while the team is working on the design project.

This framework is proposed for conceptual design projects because of certain characteristics of these projects. These design projects are open-ended and complex while we propose a validated inquiry method for analyzing its underlying work units and relations in order to accomplish the project in terms of its tasks, so it would make it possible to staff the project team effectively and efficiently. On the other hand, dynamic characteristics of these projects with team members from a broad range of backgrounds need a model which is capable of describing the design phenomena, individual and team performance among the design team.

We applied this framework in a conceptual design project to demonstrate its effectiveness and validity. Implicitly, the results have shown that EBD can be an effective methodology for being used by a design team to solve the conceptual design problem effectively and efficiently as the evaluation of final delivered solution promises.

6.2. Future Research

One of the limitations of this study is where an organization has more than one project available and wants to assign its available staff to more than one project. This setting turns to a two-sided matching problem in which one side consists of projects while the other side stands the organization's staff and the organization

matches two sides to their best preference. There is a vast amount of articles about two-sided matching literature while recently Google has implemented such model in its organization [68] and Xu has provided a model which is suitable for dynamic settings of a matching problem [69] which can be applied in this context.

We have proposed a model which is capable of describing the relationship between the perceptions among team members and team performance. We have synthesized this model from the literature which is available on mental models and creativity models. Intuitively, this model is working fine, and it can effectively describe the design phenomena in the design team according to our case study. More experiments can be conducted to support the model's accuracy in describing these phenomena.

Nowadays, many projects adopt agile project management practices like agile methodology or Kanban, especially in software and IT projects in which requirements change gradually over time, and even sometimes details about further steps are not that clear. The models that we have described are based on a design setup in which the design problem remains similar over time. This specific setting can be studied further to find out about implications of changing requirements by the stakeholder and how to manage it.

While our case study and its evaluation can support our research, having more case studies can make it possible to analyze the results statistically which may support the results significantly.

Publications

Conference Papers:

1. *Ommi, Y. Zeng, and C. C. Marsden, "DESIGN PROBLEM PERCEPTION IN ENGINEERING DESIGN TEAMS," in Proc. 2017 Canadian Engineering Education Association (CEEA17) Conf., 2017.*

2. *Ommi and Y. Zeng, "DEFINING THE APPROPRIATE COURSE PROJECT FOR FOSTERING THE EXPECTED COGNITIVE COMPETENCIES: EBD APPROACH TO AN ENGINEERING DESIGN COURSE," Proc. Can. Eng. Educ. Assoc., pp. 1–9, Dec. 2018. (Full Peer Reviewed Paper)*

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Appendix A – Case Study Events and Schedule

This appendix provides important events throughout the design session along with a data collection schedule in Table 34 and Table 35 respectively. This can also be used for further analysis of the collected data.

Table 34 - Events schedule for the case study

Date	Topic	Time	Location
6-Jul	Kickoffs	-	EV 9.235
11-Jul	Architecture Eng. cohort Kick Off	1:00 PM	EV 9.235
12-Jul	Mechanical and aerospace cohort kickoff		
13-Jul	Electrical Eng. Cohort Kick Off		EV 9.235
26-Jul	Deadline for submitting 1st round design results		
31-Jul	EBD Training	9 - 12 AM	EV 9.221
3-Aug	Deadline for submitting the 2nd round design and criteria for other groups		
4-Aug	Sharing 2nd round design with all team members		
7-Aug	Conflict Identification	9 - 12 AM	EV 11.119
14-Aug	Conflict Resolution and integration	9:30 - 12 AM	EV 11.119
			EV 9.235

Table 35 - Data collection schedule for the case study

		Assignment Time	Collection Time	Filled by	Collection Date
1	Survey 1 Part A	During kick-off meetings	Before Interview	Designers	6-Jul-17
2	Survey 1 Part B	During kick-off meetings	Before Interview	Designers	6-Jul-17
3	Survey 1 Part C	During kick-off meetings	During Interview	Interviewer	6-Jul-17
4	Initial Design Alternatives	Kick off	Deadline	Design Sub-teams	26-Jul-17

5	Survey 2	Beginning of Session	Before Lecture	Designers	31-Jul-17
6	Evaluation criteria for other sub-teams	During EBD Lecture	Deadline	Design Sub-teams	4-Aug-17
7	Updated Design Alternatives	During EBD Lecture	Deadline	Design Sub-teams	4-Aug-17
8	Survey 3	Beginning of Session	Before Discussion	Designers	14-Aug-17
9	Final Design Solution	During the Last Session	Deadline	Design Team	5-Sep-17

Appendix B – Final Design Solution

Final design solution which is submitted by the team is presented in the following figures

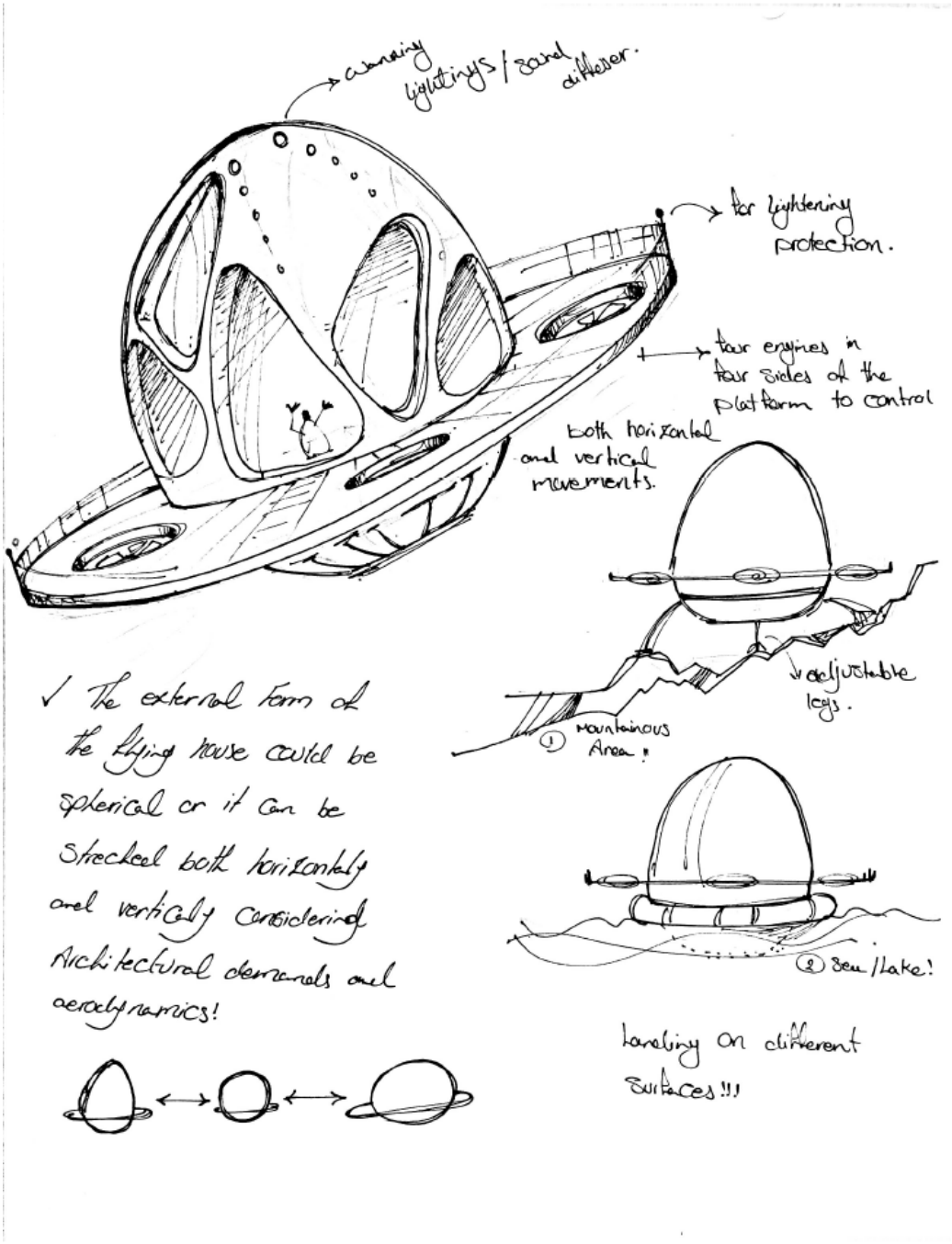

Figure 31 - Final solution for the flying house design project - 1

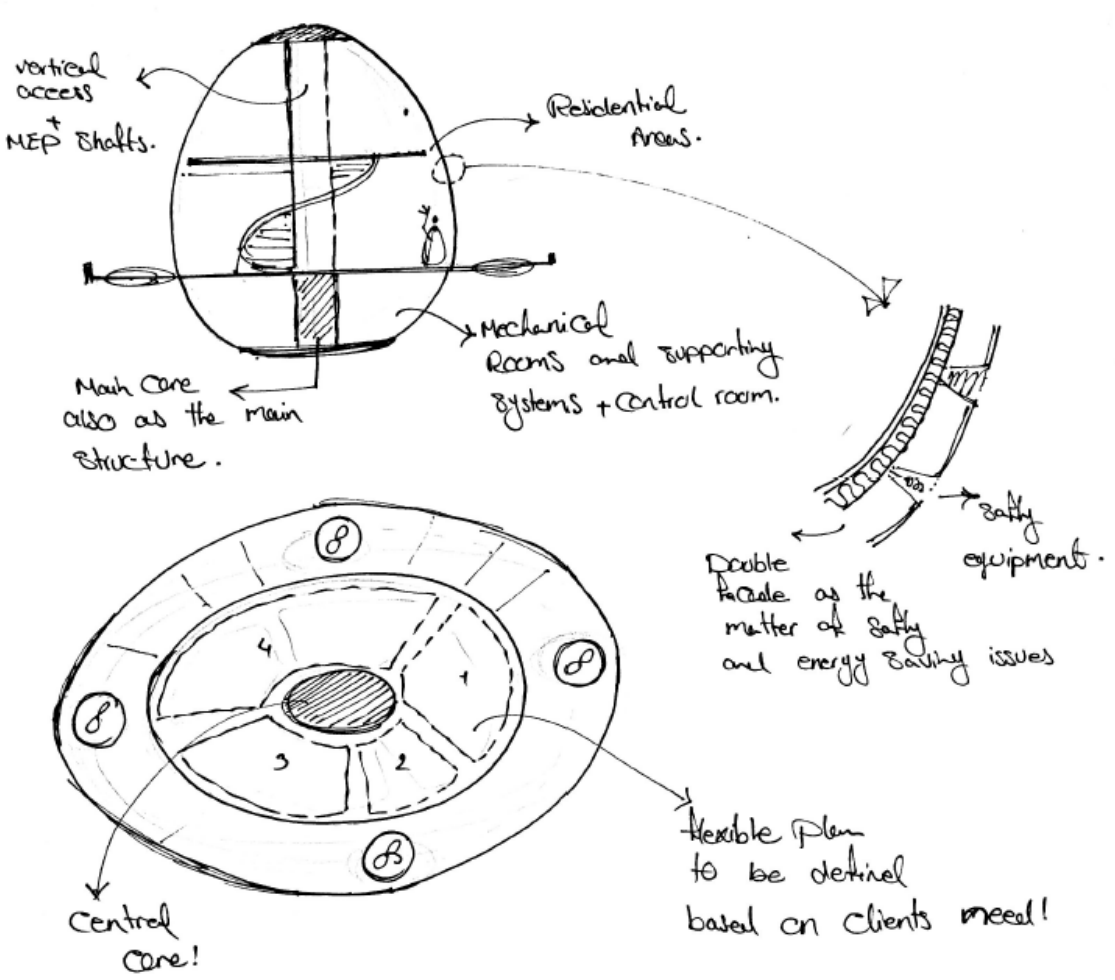

Figure 32 - Final solution for the flying house design project - 2

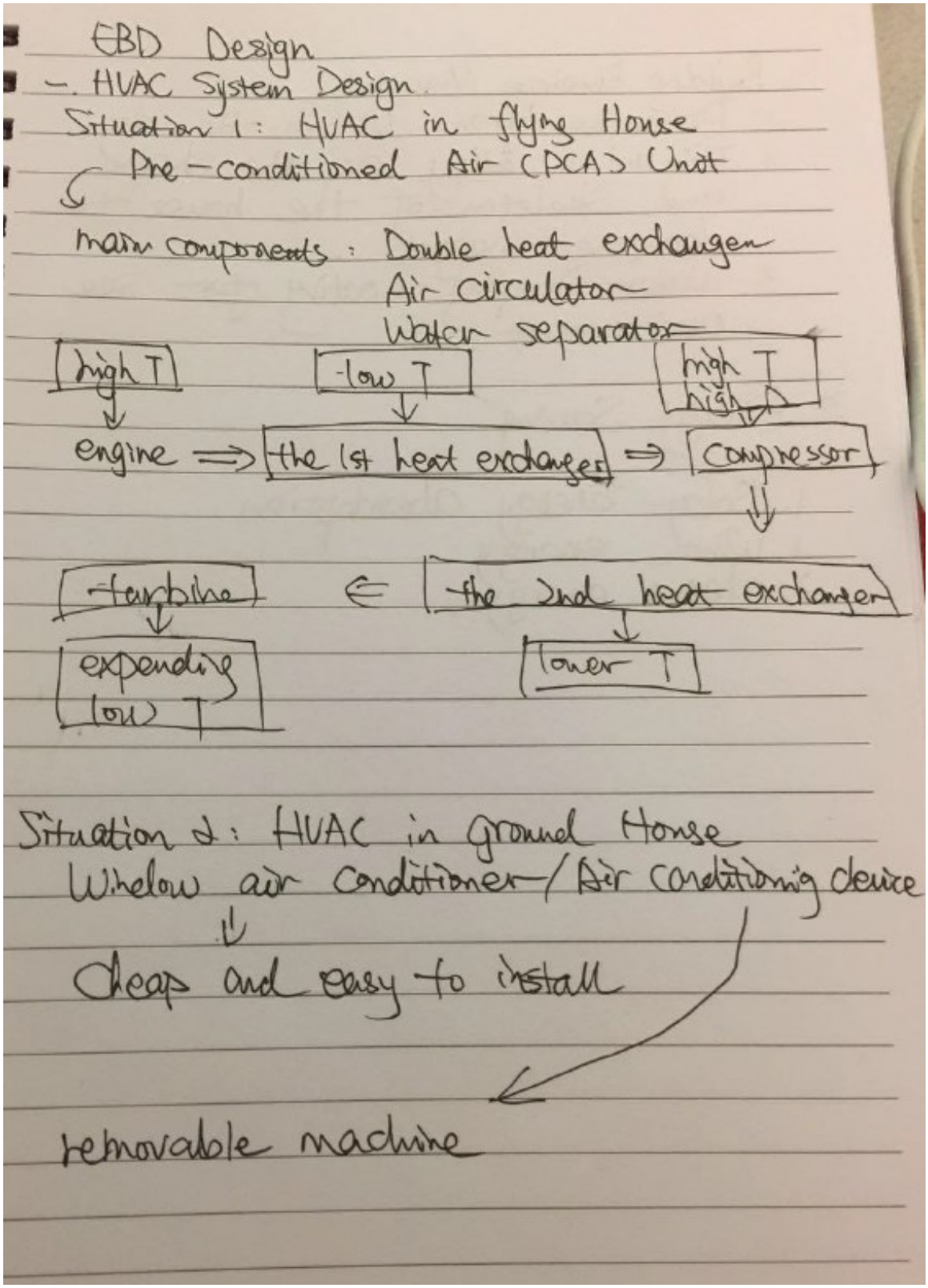

Figure 33 - Final solution for the flying house design project - 3

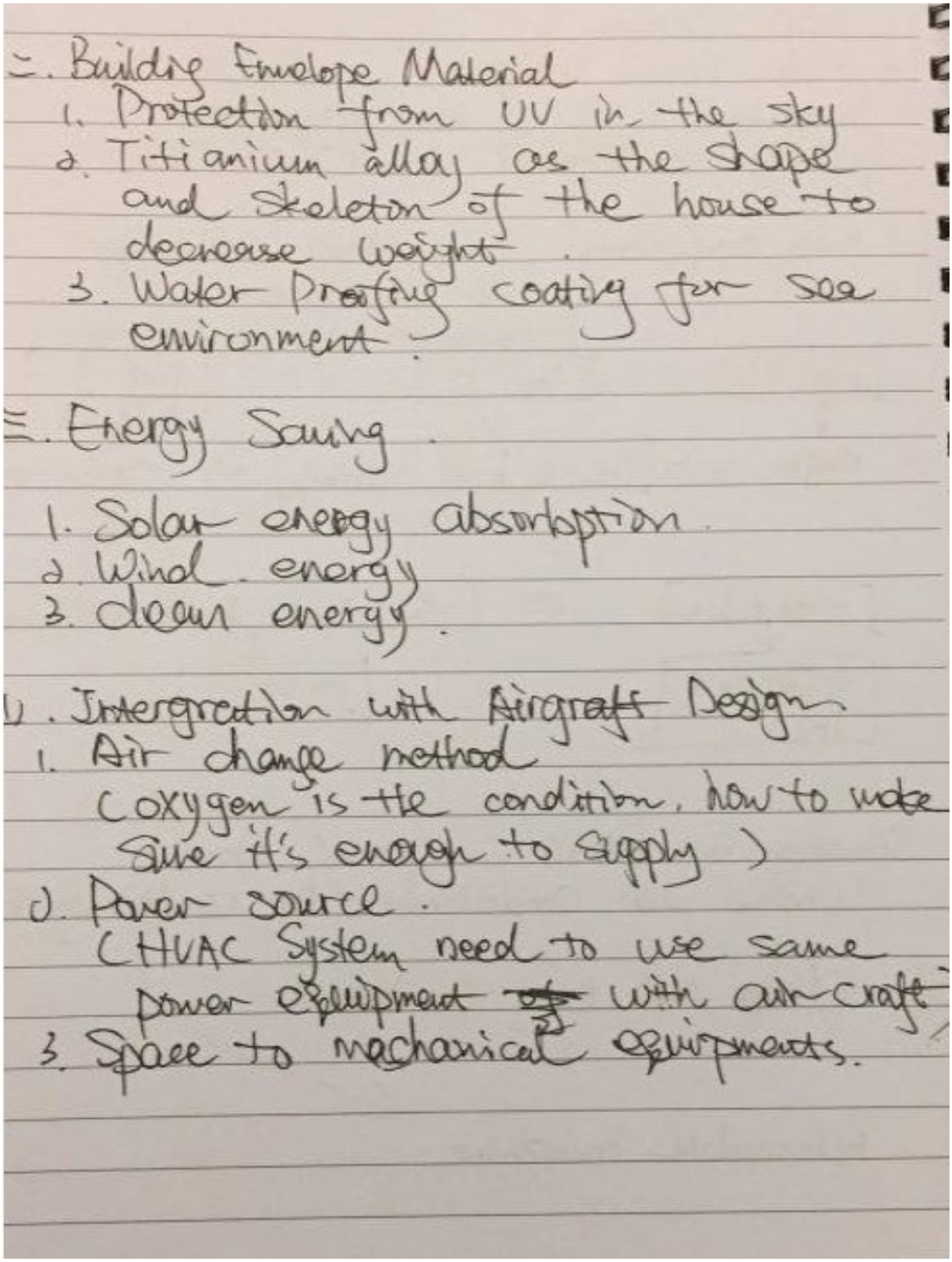

Figure 34 - Final solution for the flying house design project - 4

Appendix C – Consent Form

The consent form which is signed by participants in our case study is presented in Figure 35 and Figure 36.

CONSENT FORM FOR PARTICIPATION IN DESIGN EXPERIMENT

This is to state that I agree to participate voluntarily in a program of research being conducted by Mr. Amirali Ommi, a Master student and Xiaoying Wang a PhD student both in the Concordia Institute for Information Systems Engineering (CIISE) under the supervision of Dr. Yong Zeng in Concordia Institute for Information Systems Engineering (CIISE) at Concordia University.

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A. PURPOSE

The purpose of this research is to study designers' design activities during the design process by using the following devices:

1) Video cameras, and/or
2) Audio recorder.

The result of this research will be used to study how EBD can help the design team to generate design product as well as improvement of design project management.

B. MEASUREMENTS

The data will be collected throughout an experiment of doing a conceptual design to be conducted on Campus of Concordia University. The following data may be recorded:

- Design log book;
- Design sketches;
- Meeting minutes; and
- Video and audio recordings of group meetings.
- Surveys and Questionnaires

C. RISKS

There will be no risks in this research.

D. CONDITONS FOR PARTICIPATION

My participation in this research is voluntary. If I decide not to take part in the project, I am free to discontinue at any time without adverse consequences. My personal information will be kept confidential.

Figure 35 - Consent form signed by case study participants – page 1

• I consent to be video-taped during the experiment.	☐Yes	☐No
• I consent to be audio- taped during the experiment.	☐Yes	☐No
• I understand that the data from this study may be published; but all my personal information will be kept confidential. My identity will not be disclosed or related to any result in any publication unless my written permission is obtained.	☐Yes	☐No

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT.
I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICIPATE IN THIS STUDY.

NAME (please print) _____

SIGNATURE _____

WITNESS SIGNATURE _____

DATE _____ **TIME** _____

If at any time you have questions about your rights as a research participant, please contact Adela Reid, Research Ethics and Compliance Officer, Concordia University, at (514) 848-7481 or by email at areid@alcor.concordia.ca.

Figure 36 - Consent form signed by case study participants – page 2