AMERICAN UNIVERSITY OF BEIRUT

HOW ORGANIZATIONAL PROJECT ROLES INTERACT WITH CAD TECHNOLOGY CHANGES: AN EXPLORATORY CASE STUDY OF A MIDDLE EASTERN ENGINEERING DESIGN FIRM

by
JEAN JAD LAHAM

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JEAN JAD LAHAM

Approved by:

Dr. Bizhan Azad, Associate Professor — First Reader
Suliman S. Olayan School of Business

Dr. Yusuf Sidani, Associate Professor — Second Reader
Suliman S. Olayan School of Business

Date of project presentation: May 15, 2013

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AN ABSTRACT OF THE PROJECT OF

Jean Jad Laham for Master of Business Administration
Major: Business Administration

Title: How Organizational Project Roles Interact with CAD Technology Changes: An Exploratory Case Study of a Middle Eastern Engineering Design Firm

Prior (ethnographic and qualitative) research on organization-technology change has provided us with insights into professional role changes that take place as the organization transitions from one work technology configuration to another. Barley's (1986, 1990) work on introduction of new digital medical imaging into two hospitals is foundational from this perspective. As the economy and society have become more knowledge-intensive, the rhetoric/hype about the knowledge work is all around us. However, this hype has rarely been matched by research that is grounded in the reality of knowledge work and the concomitant role/procedure changes—to inform management research and policy. Furthermore, two aspects of the underlying phenomena have been under-explored: engineering technical settings and Middle Eastern organizational practices.

This MBA project addresses the above gap in research including the engineering setting and Middle Eastern context. We analyze how the role and knowledge content changes of Engineers and Technicians at a major regional firm (Alpha Middle Eastern Engineering) is transitioning from employing AutoCAD® to using Revit® in its drafting and design practices—AutoCAD software has a traditional structure consisting of points, lines and polygons while Revit's structure is object-oriented consisting of design objects (e.g. doors, junction boxes, circuits, roofs, etc.). This analysis reveals three distinctive patterns of knowledge content and role change due to the transition: knowledge mixing; task/work load change; and role-knowledge-stickiness. First, we observed a pattern of knowledge mixing among the engineer and draftsperson role. The engineers appeared to have taken on to do some of what draftspersons used to do, while draftspersons are taking on to do what engineers used to do. Second, task/work load of engineers has increased while the draftspersons' task/work load has decreased. Third, there is increased role-knowledge-stickiness to the draftspersons' practices. Before Revit, they could be deployed among different projects and systems very easily, since their know-how was about manipulating points, lines and polygons. However, subsequent to Revit's introduction, the knowledge content of their work has increased: to use HVAC objects in Revit they need HVAC knowledge, which is not the same as Circuit Design knowledge. These patterns of change in roles nicely illustrate that knowledge content changes on the ground differentially emerge for engineers and draftspersons. The draftspersons appear to experience some upskilling (need to have more design knowledge). The engineers appear to experience to some workload change but also some downskilling (need to know software use).

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CHAPTER I

INTRODUCTION

Introducing, and adopting, new technology into a work process is a very frequent phenomenon in the present day business world, especially given the fast pace of technological developments in most sectors. Most of the time it comes down to the company's aspiration to increase performance, often due to either external or internal forces. While this demand may be a sound reason to drive a firm to take a decision to adopt a new technology, firms do not always consider the socio-technical or sociomaterial (we use these interchangeably) effects that the new technology will impose (Orlikowski & Scott, Sociomateriality: Challenging the Separation of Technology, Work and Organization, 2008). Technology is often accompanied by a reconfiguration of "boundary dynamics" between different job roles (Barrett, Oborn, Orlikowski, & Yates, 2012). This reconfiguration is influenced by the introduction of the new technology into a work process and renders the process to behave non-linearly. This means that it is often not a one-to-one relation, whereby a given input will determine the same output. In saying this there is a claim that technology's sociomaterial effects are not fixed: these are time- and space-variant. In some cases the use of technology causes the restructuring of organizational relations (Barley, Technology, power, and the social organization of work., 1988). Besides the fact that technology is changing at an increasing rate, it is increasingly more complex. Bechky (2003) states that "with the development of progressively complex workplace technologies, technical knowledge has become an imperative of organizations". To better understand these effects we need to study the process of change that takes place on the ground regarding job roles, the nature of the associated tasks, and the knowledge required to do so.

This paper focuses on the effects of the change in the drafting and design process that engineering and technical staff use to perform (knowledge) work, and the consequential reconfiguration of job role “boundary dynamics” that are brought about by introducing a new CAD technology into a Middle Eastern engineering design firm, Alpha. The objective of this paper is to highlight the consequences that the new CAD software sets in motion on different job roles in the company, as well as the way that employees carry out the tasks to their jobs, and how a need for role re-definition is brought about because of these changes. This phenomenon is studied via the “practice lens” approach on job roles, role interactions, and workload distributions of the employees of Alpha. In the study three patterns emerge, as resulting effects of the new CAD technology’s adoption. This research offers an in-depth view of how these changes take place on the ground, and how they redefine the knowledge requirements of the tasks that employees would be responsible for, and how they can lead to an organizational restructuring of the firm among its professional cadre of staff.

A. Construction Industry and Information Technology

The Architecture, Engineering, and Construction industry has been using CAD technologies. Usually a project would consist of at least two organizations each with their respective responsibilities, the designer and the contractor. Designers are responsible for developing a design that meets the requirements of a project, as per the project’s contractual terms and conditions. After a design is developed, a contractor is hired in order to implement the designed system(s) on the ground. CAD drawings were the default form of technical communication between these different parties when collaborating on an engineering construction project. The purpose of these drawings is to communicate design specifications among stakeholders.

The design is represented by the use of engineering symbols and design conventions to illustrate the design on a set of drawings and plans that represent the final layout of the project. These designs are implemented by the means of using computers and CAD software. And so, the common practice in design firms in the construction industry is referred to as Computer-Aided (Software) Engineering, or CASE (MBA Knowledge Base). One of the most popular commercially available CAD applications used in the engineering industry is AutoCAD. This application is a drafting application that is usually used by draftspersons, to represent the engineering system that is developed by the engineers. The new trend, however, in the construction industry today is towards modeling, away from drafting.

In particular, a growing trend in the engineering construction industry is the use of Building Information Modeling (BIM). BIM may be referred to as an evolution of the legacy engineering drafting practices that were previously used; and sometimes still used today. The concept behind BIM is to produce a fully functional virtual model of the final project that is being designed in an interactive, integrated, and coordinated manner. BIM is seen as a holistic approach to design engineering and modeling that integrates the project lifecycle, between, project management, design engineering, architecture, and the final construction (see Figure 1).

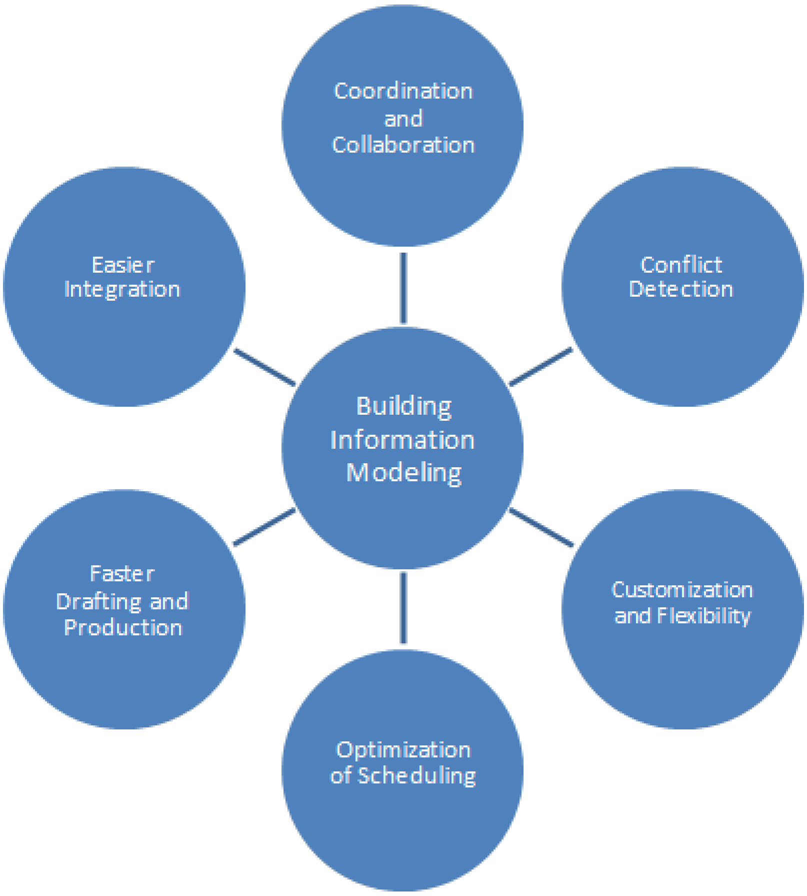

Figure 1. The different components of Building Information Modeling.

One of the leading software applications used for BIM today is Revit. The software provides designers of different engineering trades to collaboratively work on a single distributed platform in real-time, in order to produce a final functional model of a given project. After the model is designed, coordinated, and finalized, it may be handed over to a contractor, in order to carry out the necessary works to implement the project.

As a sophisticated piece of technology that is more integrative, BIM software is also more intelligent. A simple example is to say that in the previous case with AutoCAD, a draftsperson, could draw any drawing that consists of lines, circles, and arcs. When working with BIM software, the user interacts with it in a manner where the software ‘understands’ the different components of a design. And therefore, is the user wants to install a door in a certain wall, in order to create a passage way between two areas, they would ‘instruct’ the BIM software to do so. This is to say that the software ‘understands’ what ‘a door’ is, versus ‘a wall’, versus ‘a window’, etc. This clearly indicates an increased requirement in the technical knowledge of the user, in order for them to be able to interact with the software.

B. Research Objective & Research Questions

The objectives of this research are concerned with the changes that are brought about by the adoption of the new CAD software, the changes it brings about in employees’ job roles, how it effectively changes the process through which people do their work, and how it can entail an organizational restructuring to the firm’s professional ranks. Through the course of the data collection, semi-structured interviews were carried out with a number of employees of varying roles in the company. A comparison is then made of the two scenarios when using the old CAD software versus the new CAD software. The comparison focuses mainly on the different work tasks that employees were responsible for in each of the scenarios, how these work tasks are executed in each scenario, the knowledge work requirements of these tasks, and *how* these redefinitions essentially alter *the process of work by the employees*. Through these interviews we understand the specific job roles and tasks that were embedded with the process when using each CAD application. These changes highlight patterns and trends that lead to job role boundaries’ reconfiguration. We also illustrate how management has intervened to deal with these changes in order to adapt to this emergent “social order”. The term “social order” is synonymous with “the general idea of a social pattern or regularity" in the workplace (Barley, 1990).

The above research objectives lead to the following research questions that have guided our data collection and analysis:

- What are some of the specific "material" or non-relational changes in going from AutoCAD to Revit that appear in processes and routines of job roles at Alpha engineering firm (highlighting specific changes in work packages that are different under AutoCAD vs. Revit)?
- How does the introduction of the new CAD software bring about these process changes, and how do they influence the methods previously used by the employees of the firm?
- What effects do these process changes have on the everyday tasks of the core functional employees of the firm?
- How have these changes influenced the way people are taking on work, to meet their job responsibilities?
- How have these changes new knowledge requirements on the people that are performing the work?
- How has the management of the firm responded to these changes and their emergent dynamics?

CHAPTER II

LITERATURE REVIEW

In this section we will summarize the prior research on studying technology's influence on organizations. Early research in the field by authors such as, Hickson, Pugh, Pheysey, Mohr, Blau, Gerwin, and Fry, was considered to be confusing and contradictory in nature (Barley, 1986). This research covered some of the preliminary works of technology in the organization and the influences that it has on organizational structures. Most of this research was carried out after World War II. One of the dominant notions when discussing such subjects is the emergence of "structure". In these earlier works structure was used in a sense to convey "abstract, formal relations that constrain day-to-day action in social settings" (Barley, 1986). Two theories that exist today to make a link between structure, technology, and organizational structures, are negotiated-order theory, and structuration theory.

Strauss (1982), articulates negotiated-order theory to be a product of the actions of communication, interpretation and the reactionary adjustments between individuals to establish a form of order. This theory looks at these elements from the perspective of events that take place in everyday life.

Contrasting with this theory, sociologist Anthony Giddens (1979) presents another theory, which is the structuration theory. This theory deals with the formulation of "social systems", based on the actions and interactions of the participants of the model, the structure and the agents. From this basis he proposes that in order to understand structure, one must acknowledge it as having a dual nature, whereby it is a medium as well as the product of social practices and interactions (Giddens, 1979).

As a result of these theories, Barley (1986) claims that there is a basis to enact structure as both a process and a form. Furthermore, he goes on to say, “structuring involves investigating how the institutional realm and the realm of action configure each other” (Barley, 1986). This statement aligns with Giddens’ structuration theory, in that it takes the form of a structure and its agents, and how each influences and interacts with the other. Barley goes on to state that “technologies exist as objects in the realm of action”, and that in order to understand the implications of a certain technology on a certain structure, one must also investigate how this technology is integrated and interacted within the everyday life of the members of the organization (Barley, 1986).

Later on, Roberts and Grabowski (1999) build on the concepts of structuration theory, and they propose a dual nature for integrating technology as being both “a product and a process”. This dual nature of technological integration, as introduced by Roberts and Grabowski points the way for interweaving of technology and organizational structure. Combining this view with that of Barley, we can deduce that in order for one to study technology’s influence on organizational structure, one must study the focal phenomenon as both the ‘process’ and the ‘product’.

Roberts and Grabowski (1999) categorize the extant literature into two streams: (a) the descriptive view and (b) the relational view. The descriptive view covers research that addresses technology as having a type and a role within an organization. The relational view on the other hand, relates more to the previous notions of Giddens, whereby it deals with the relation between technology and structure. It is argued that these two views need to be integrated in order to build the basis of a solid research stream that promises a productive way for work for the field. Taking IT as the most predominant form of technology that has weaved its way into most organizations today, the research was focused on how IT was transforming the tasks of "coordinating and controlling activities" (Roberts & Grabowski, 1999).

In 2008, Orlikowski and Scott, summarize the previous research in the field on technology and its integration and influence on organizational structures in the article titled "*Sociomateriality: Challenging the Separation of Technology Work and Organization*". Building on Roberts and Grabowski argument that previous literature requires some form of consolidation, they introduce the concept of "sociomateriality" (Orlikowski & Scott, Sociomateriality: Challenging the Separation of Technology, Work and Organization, 2008). The concept of sociomateriality challenges the prior research approach which has attempted to separate "technology, work, and organizations", claiming that these entities are "inherently inseparable" due to the interconnection of their social and technical attributes.

Other authors, such as Suchman (2007) study such dynamics concerned with the sociomateriality of everyday practices found in organizations, such as the use of photocopy machines, robotics, and even computer-aided design (CAD) software. In the case of an engineer working with the CAD software (as it is directly related to the subject of this research paper) she states that "the CAD interface becomes for the engineer a simulacrum of the site, not in the sense of a substitute for it but rather of a place in which to work, with its own specific materialities, constraints and possibilities" (Suchman, 2007). By this we see a 'configuration' and 'reconfiguration' in the engineer's interaction with the software, which she refers to as the "human-machine interface". Suchman identifies the materiality of the objects, and the relations between them and the agents utilizing them to be a part of an "embodied and material social practice" (Suchman, 2007). This observation reinforces Orlikowski & Scott's proposition of the integrated and interweaved sociomaterial nature of technology, and organizational practices.

Similarly we observe a growing trend in the field of robotics, with the rising ability of robots to replace human operators, in turn taking over their jobs in numerous settings. Examples of these settings are “factory floors, deep-sea exploration, emergency response, hazardous environments, and health care” (Lanfranco, Castellanos, Desai, & Meyers, 2004). Such technological introductions are playing a significant role in “reorganizing work among different occupational groups by, for example, altering roles and relations across diverse work contexts” (Zuboff, 1988) (Barrett & Walsham, 1999). Barrett et al. (2012) protest that there is a lack of real world practical “accounts” of “what happens when multiple occupational groups influence each other as their work and relations are restructured around a new digital innovation”.

Computer-Aided Design (CAD) technologies are vital components of the engineering sector today, and are becoming more and more integrated in the design processes of engineering systems. Because of this, we believe that by studying the process through which sociomaterial relations take shape on the ground, and how these technologies are interacting and transforming the conduct of work and dynamics of organizations, is a valid and crucial account for the advancement of research in this field.

Mentions of CAD technologies in engineering practices relate directly to the literature on “knowledge work” and the case to be presented in this research. Engineering design firms by their nature are knowledge intensive firms that operate in the confines of technical knowledge, and thus are highly reliant on “knowledge work” as well as “knowledge workers” (i.e. the engineers); it is the basis of their core competence. Considering the sociomaterial changes brought about by the adoption of new technology into an engineering firm, leads to the need to study the improvement of knowledge work processes in the organization as a reaction to this adoption of the new technology (Davenport, Jarvenpaa, & Beers, 1995).

In this paper we employ a practice lens approach to study the interdependent nature of technology, organizations, and organizational structure (Orlikowski, 2000). From this we examine an account on the methods in which these interactions are shaping and reshaping an organization today in the engineering construction sector. This study focuses on the introduction of a new digital innovation (in the form of a new CAD technology) into an organization and the everyday tasks carried out by its professional/technical employees to do their work. The process is studied from a human-machine interaction point of view, as well as the effects that implicated on a human-human level of interaction.

CHAPTER III

CONCEPTUAL FRAMEWORK

This research is based on the occurrence of a phenomenon in a single firm; an embedded single-case research method shall be employed (Yin, 1990). Orlikowski and Scott (2008) develop the concept of sociomateriality in their article "Sociomateriality: Challenging the Separation of Technology Work and Organization", to emphasize the importance of technology being an inseparable component of the "technology, work, and organizations" triumvirate. Meanwhile, the article also reinforces the "inherent inseparability between the technical and the social" aspects of work in an organization. It points to a more "relational view" between technology and structure, and leads to the notion that technology is somewhat analogous to the DNA of an organization. This is to say that it is so deeply integrated in the methods and tasks that are performed on a day-to-day basis that extracting it to study, observe and analyze it independently is theoretically ill-advised. These tasks essentially depend on a given skillset, or know-how, in order to be carried out, and this knowledge is to be directly related to the conduct of work. The framework used to analyze the phenomenon that takes place in the present case, is based on the relationship of the knowledge requirements to execute a given task, the classification of that knowledge, and the corresponding nature of those tasks. The following figure (see Figure 2) illustrates this pseudo-causal approach and is presented in this paper as a framework to be adopted in order to portray and analyze the change effects that appear in Alpha Engineering Design Firm, as they introduce a new technology into their core operational process.

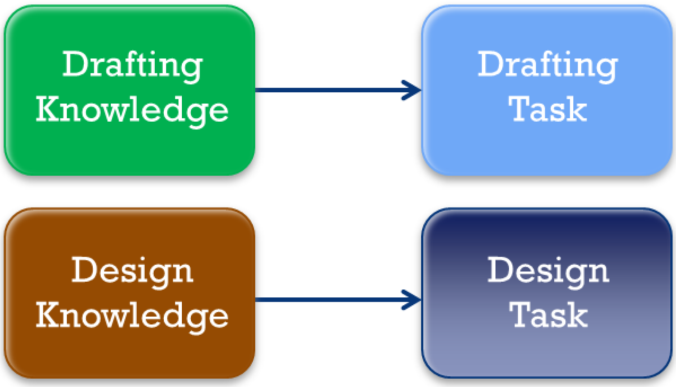

Figure 2. The framework relating the knowledge classifications to the job tasks required to carry out those tasks.

The new technology is a Building Information Modeling CAD application, which is used for producing their engineering designs. This CAD application is meant to replace the previous CAD application (old technology), which is more of ‘drafting software’ rather than ‘modeling software’. The framework focuses on the day-to-day work tasks of the draftspersons and the design engineers (the attributes of the nature of their work), and examines the dependence of the nature of work tasks on their corresponding knowledge classification.

This framework was used to guide the data collection methodology, which is detailed in the next section. The analysis is used to examine the design work units within the firm by identifying the change in the nature of the workload assigned to the different members of the design unit, throughout the adoption process, and examining how the new technology necessitates knowledge change requirements on the different members of a design work unit.

CHAPTER IV

METHODOLOGY

A. Research Approach

This paper takes on an exploratory approach to achieve the research objectives. The research questions are formulated, in order to achieve these objectives, and focus on the practical occurrence of the phenomenon at hand, on the ground. Based on the company's organizational structure, the employees were profiled based on their job title, the department that they belong to, their experience when working with the new CAD software, as well as their experience when working with the old CAD software. We selected a number of interviewees, planned space and time of interview based on the mutual agreement.

The research approach predominantly assumes the form of open-ended "focused interviews" with the interviewees (Yin, 1990). These interviews were planned and executed based on a set of interview questions. The objective of the questions was to serve as a guide to drive the discussion in the direction relevant to the research. As the discussions were carried out, the interviewer also attempted to probe for data in order to discover the potential underlying 'hidden truths' that could shed more light on the underlying phenomenon. The interview questions were formulated by breaking down and elaborating the research questions of the paper into a more practical form. As the research questions were initially set out to provide the answers needed to achieve the research objectives, inductively the interviews could potentially provide the data required to answer the research questions.

The research methodology adopted in this paper is based on the case study approach. The intent behind selecting this approach is to answer the research questions concerned with the "how" and "what" questions of the research (Yin, 1990). Furthermore, this approach was also selected as the preferred method due to its innate ability to bring focus to the contemporary events, which are being studied in this research (Yin, 1990). Therefore, this research presents the case of a single engineering design firm that is located in the Middle East region.

The research is concerned with studying the internal dynamics of the firm and how they change with the introduction of new CAD technology into the firm. These changes occur at a functional level, where the main focus is on the job roles of engineers and draftspersons. Evidently this implies that the units of analysis of interest in this research include roles and tasks. Also since the analysis will focus on the outcomes of the studying these roles and tasks. This renders the study to be an embedded case study (Yin, 1990).

B. Data Collection

The main methods used to acquire the data were the use of semi-structured interviews, as well as direct observation. Employees of a number of different grades were interviewed on a one-to-one basis, whereby a discussion was held, for duration of approximately 30 minutes per interview. The roles of these employees included draftspersons, design engineers, project engineers, and managers, from the two main engineering departments in the firm. These two departments are the mechanical department, and the electrical department. A description of each department, the kind of work that is carried out in each, and how processes are executed will be discussed in the following chapter. The research was focused primarily on the work tasks of the design engineers and the draftspersons of each department, because this is where the phenomenon in question takes place from one day to the next. These sets of employees were selected based on their experience of having worked with AutoCAD, and then shifting over to Revit. The semi-structured interview-based discussions revolved around each employee's position and how they contribute to the research. Managers were also interviewed in order to explore the awareness of the managerial body of the changes taking place. It was also of interest to examine, if there were any plans put into play by management to deal with these changes, and for how they were intending to do so. They were interviewed in the same fashion as the other interviewees, whereby a semi-structured interview-based discussion was carried out. The distribution of the number of employees, per job role, is illustrated in the following table.

Table 1: Profiles of Interviewees

Department	**Quantity**	**Position**
Mechanical Engineering	1	Manager
	2	Project engineer
	2	Design engineer
	2	Draftsperson
Electrical Engineering	2	Manager
	2	Project engineer
	3	Design engineer
	2	Draftsperson

Throughout the interviews, there was a distinguishable notion that the engineers and the draftspersons were indeed aware of the problems that they were facing. While some of the engineers took these changes with a positive attitude, claiming that the new CAD software, in and of itself, is more advanced as a CAD application, others did not. Other engineers looked at their actual workload, despite the new CAD application being advanced or not, and saw it having a negative impact, as they were not "finding enough time to do the work that [they are] supposed to do, versus the work that they now have to do". Draftspersons tended to share the negative notion, as the second group of engineers, but more so that they were being underworked, or that the work that they were given was overly simplistic that it seemed like they were getting the 'leftovers'. This information was obtained often after probing why or how their workload changed.

C. Data Analysis Protocol

The strategy adopted to analyze data first deals with organizing the data into a form that presents itself clearly and coherently. The interviews with the different employees were transcribed from the recordings that were made during the interviews. The main construct that was used to relate all the interviews together was based on the flow presented by the interview questions. The basic chronological flow of the discussions took a similar form with each of the interviewees, due to this structure. Therefore, the data was then consolidated and categorized per interview question, and per job role.

In a broad sense the research adopted a "pattern-matching" strategy in order define the outcomes that are presented, and their causal relationship to the antecedent conditions of the research (Yin, 1990). Various analytical techniques were used, in order to categorize the data so as to draw the conclusions from it, such as flow charts, tables, and process models (Newman & Robey, 1992). These conclusions are based on identifying and pointing out the underlying relations and patterns in the data, and matching those patterns with the literature. This effectively concludes the analysis section of this paper, and sets out the identified for further discussion.

CHAPTER V

CASE STUDY

The case study presented as a part of this research paper, deals with the description and elaboration on the organizational structure of the firm, as well as the tasks of the employees on an everyday basis. The firm that was studied for the sake of this case study is a multinational multidisciplinary engineering design firm. By multidisciplinary it is meant that the firm comprises of departments of engineers, and takes on engineering work, that is concerned with multiple disciplines of engineering. The industry of this firm is Architectural, Engineering & Construction industry, in that they take on construction project, and provide multidisciplinary designs for these projects. To say this means that the firm is involved with carrying out design work, versus actual construction work. The latter is a form of work that is usually carried out by companies that are termed “Contractors”. In contrast, Alpha is considered to be a design consultancy firm, frequently referred to as the “Consultant”.

The following sections of this chapter explain the departmental structure of the Alpha engineering design firm, with a focus on the focal departments and more so the core engineering design unit, which appears to be the core building block of the firm’s operations. After the framework has been set out to understand the setting of the firm and the steps that take place in the design process, an overview is presented of the importance of CAD software and how deeply entwined it is with the operations of the firm.

A. The Departmental Structure

The firm is composed of two kinds of departments, those that are engineering/technical departments, and those that administrative, or what is sometimes referred to as ‘support services’ departments. Being that this firm is a multidisciplinary engineering firm, it holds more than just a single engineering trade as part of its operations. The technical departments mentioned are as follows:

- Architecture
- Electrical Engineering,
- Geographic Information Systems (GIS),
- Mechanical Engineering,
- Resources & Environmental Engineering,
- Structural Engineering,
- Transportation Engineering.

The non-technical departments that provide support services to the employees of the firm are as follows:

- Accounting,
- Administration,
- Human Resources,
- Information Technology,
- Travel.

The focus of this case study will be based on the technical departments, as this is where the phenomenon of interest is taking place, and more so in the departments associated with designing mechanical, electrical, and plumbing (MEP) systems. These departments are the mechanical engineering and the electrical engineering departments.

Each department consists of engineers, draftspersons, and technical managers. The engineers may take one of three positions: they may be design engineers, project engineers, or group leaders. The draftspersons have a two-stage hierarchy, which is based purely on seniority. The managers are positioned as the head of their respective departments. The reason why they are referred to as technical managers is due to their technical proficiency as departmental leaders.

Members of the mechanical engineering department are responsible for the production of mechanical engineering system designs. These systems are the heating, ventilation and air conditioning (HVAC), plumbing, drainage, and control (building management) systems. Likewise, the members of the electrical engineering department are responsible for the production of electrical engineering system designs. These systems are the power distribution, lighting distribution, telecommunications, fire detection & alarm, video surveillance, access control, intrusion detection, audio-visual, and lightning protection systems. The working unit that is then assigned to each project comprises of the

Breaking down the department structure further and studying it at a functional level, rather than a consolidated departmental level we see the formulation of engineering design units. An engineering design unit is composed of draftspersons, design engineers, project engineers, and group leader. For every project that the firm is awarded, an engineering design unit is assigned in each of the two departments to work on the project. In other technical departments teams are assigned when and if they are needed, and due to a different mode of work, based on the nature of the work that they do, the teams may take a different form. Being that this design unit is formulated based on a generic profile, we will dissect this profile, by referencing a generic design unit (for the purpose of description), which we will call the ‘core engineering design unit’.

B. The Core Engineering Design Unit

The core engineering design unit is composed of a set of draftspersons, a set of design engineers, a project engineer, and a group leader. As far as group leaders are concerned, they are much more concerned with the non-engineering, managerial, and contractual elements of the project. Due to this, we will not be discussing their role any further in this case.

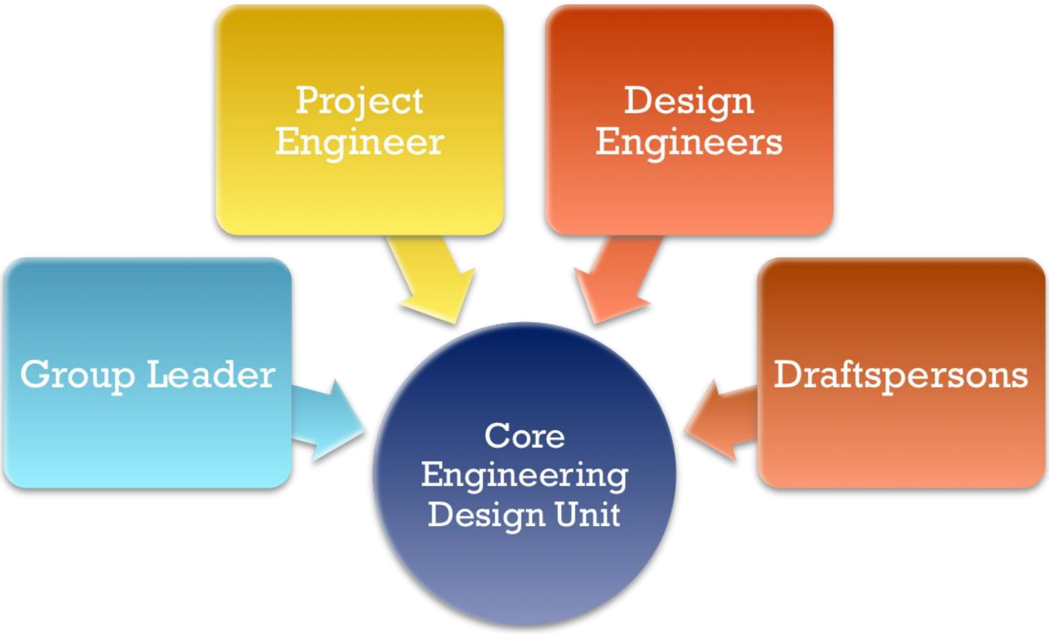

Figure 3. The different job roles that composite the engineering design unit.

The project engineer is situated between the design engineers and the group leader. They are the medium of communication between the two entities, and are responsible for ensuring a thorough, coherent, and comprehensive engineering design is implemented for all of the systems that they are responsible for. The design engineer is then situated between the project engineer and the draftspersons of the project. They are the medium of communication and translation between the project engineer and the draftspersons. The design engineers are responsible for communicating and understanding the design directives from the project engineer (this will be explained further later on), and collaborate with the draftspersons in order to translate the technical design direction that they were provided with into an on-the-ground implementation.

Therefore when we discuss the design side of any project, the design engineers and the draftspersons will be considered the core functional elements of the design unit. This is due to the fact that the final drawings that are produced are essentially a product of the design engineers' and the draftspersons' work.

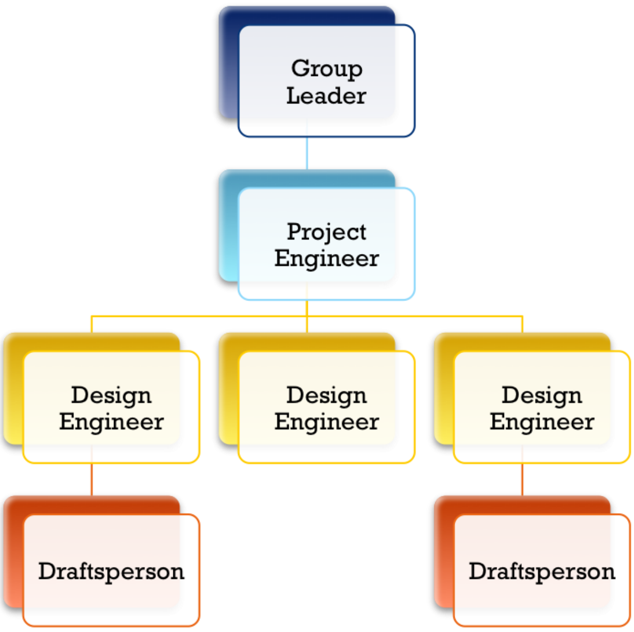

Figure 4. The hierarchy of a generic engineering design unit.

The communication protocol that is carried out between the three job roles of the draftspersons, design engineers, and the project engineer, takes on a linear form of communication and interaction. According to Figure 4 above we see that this communication protocol is represented by a vertical hierarchy, between the group leader and the project engineer, the project engineer and the design engineers, and then between the design engineers and the draftspersons. As the project engineer informs the design engineers of the design directives to be taken for a given project he is essentially communicating to them the concept that the design will be based on. An example of this, extracted from an interview with one of the project engineers is: “I would tell the design engineer, for example, that for this project we will be designing a 3-tier converged data communication network, that will be servicing data, voice, and video”. To the design engineer this implies that “the network will have a core networking layer, a distribution networking layer, and an access/edge networking layer, which is the basis of what a 3-tier converged data network is, essentially”. The design engineer then can translate this work into a floor plan design knowing that he will need to identify a “central computer room for the project; this is where the core networking equipment will be housed. Next we have one main room per building, in case it’s a multi-building project; this is where the distribution network equipment will be housed. And then we will have one room per floor, which is where the access layer networking equipment will be housed”. Ultimately all these elements, require visual design work to be represented on the plans, for example to “illustrate how the cable trays will be routed, and how the different rooms will be connected to each other”. At this point the design engineer needs to communicate these visual requirements with the draftsperson. In order to do so the design engineer sketches out hand drawings on the floor plans of the project, to indicate what needs to be drawn and where, then presents these drawings to the draftsperson. In addition to this, the design engineer is responsible for other tasks, such as performing coordination tasks with other engineering trades. Also, the engineer is responsible to communicate their requirements to other engineers of other of other trades, as well as review their work, in order to ensure that their requirements have been implemented.

In this scenario, the design engineers contribute the technical know-how and the draftspersons contribute the drafting know-how. This combination of technical and drafting know-how constitute the needed inputs required to produce a two-dimensional engineering design drawing. These design drawings are drawn on drafting software called AutoCAD. This software is considered to be CAD software that is widely used and known in the industry.

C. Using CAD Applications

The AutoCAD software is inherently engraved in the operational procedures of the organization. This is evident from the fact that the firm has "been using this software for over two decades now". A manager goes on to explain that their "work is so integrated with AutoCAD that [they] probably can't work without it". AutoCAD is drafting software that the draftspersons use to draw visual representations of the engineering systems designed by the design engineers. AutoCAD as a predominantly drafting application and not a 'modeling' application has a distinctive structure. This is to say that in order to be able to use AutoCAD, one must know how to draw with AutoCAD. This statement leads to the implication that AutoCAD is content agnostic, i.e. whether one is drawing a lighting luminaire or a telephone wall outlet, essentially the application is representing it by a group of 'points, lines and circles'. Not to belittle the software, as it is one of the most popular drafting tools available today, but in essence it is still a drawing tool and therefore, any further engineering work that needs to be done, is often done manually. Examples of such work are coordination with other engineering trades, or discovering and dealing with conflicts in the design between different components, even with other engineering trades.

Furthermore, from a modeling point of view, AutoCAD present a great tool for drafting buildings details and the support services inside these buildings. However there is no integration of these data by the software. Any such integration would be up to the user, who would need to consolidate all project files, and present them accordingly as an integrated pseudo-model.

All in all, while AutoCAD may be arguably one of the best, if not the most popular, drafting software available to the construction engineering industry. It is nonetheless just a drafting application that is structurally different from the emerging Building Information Modeling trends in the industry.

D. The Shift to a New CAD Application

This evolution from basic design and drafting tools to more sophisticated CAD applications is a secular market trend among most firms in the AEC industry. Market forces, whether they are from clients, contractors, or an internal need to evolve as an engineering design firm, are leading to the adoption of object-oriented Building Information Modeling (BIM) technologies. Two terms require further definition here, the precedence of object-oriented applications, and the concept of BIM.

With recent developments, the senior executives of the firm decided to adopt new software to be used in the design process of the firm's projects. This new software is a CAD application that redirects the course of the design process providing the firm with the ability to produce a higher quality end product. As previously mentioned, the final product that is produced from a visual design perspective is the design drawings. The new CAD application however, allows the firm to produce feature-rich designs that represent Building Information Models, rather than just basic two-dimensional drawings. These building models hold the potential to represent information that they contain in the original form, of a two-dimensional design drawing, or as an interactive digital data file.

Contrary to the use of AutoCAD and its long history in the firm (more than 25 years), Revit has only been around for approximately three years. While we introduced all the shortcomings of AutoCAD in the previous section with respect to modeling as well performing actual engineering design work versus just drafting, in this section we will introduce Revit, and how it overcomes these obstacles.

The most notable difference between the two CAD applications is the system philosophy embedded with the software. From a conceptual perspective, Revit is built from the ground up, as an object-oriented software application. This implies that the user interacts with the software by working with ‘virtual objects’. These virtual objects are referred to as ‘families’. Families are analogous, and symbolic of real-life engineering components. Therefore, the user interacts with Revit by modifying, moving, and installing virtual engineering components. From a conceptual perspective this makes a lot of sense for a designer, as they would now be capable of interacting with the software in a realistic manner similar to what is expected to exist after construction has complete.

AutoCAD works with drawings on a computer file basis. Therefore, every file may be a two-dimensional drawing, or a set of two-dimensional drawings combined into one single file. Contrastingly, Revit works with building models. Therefore a single Revit file may contain the information required to represent a building model. The primary element in a Revit file is the actual model and all of its physical and technical attributes. Drawings are then seen as a product that may be exported, depending on how the user decides to show the model. On the most basic level, it is clear that while AutoCAD is a drafting application, accordingly Revit is modeling software.

Being that the Revit works with building information models, intrinsically implies that it is "content aware". Since the components are arranged in families, they are virtual representations of engineering systems, which makes the software capable of making 'relations' between the different virtual components. An example of this is if we take a light switch that is installed on a wall; Revit is able to associate this specific light switch, which is universally identifiable in the application, with the wall that it is installed on. Following such logic, Revit is also 'smart' enough to detect whenever devices overlap each other, across all systems, since they are all being shared in the same model. This feature reformulates how the design engineer needs to coordinate with other engineering trades, in order to ensure that any such conflicts are dealt with. Instead, the software can carry out this task for them.

From an operational point of view, the personnel that will be utilizing this new CAD application will undoubtedly be the subset of the design unit that is responsible for producing the design drawings; that is the combination of the design engineers and the draftspersons. Viewing the design process and tasks from the bottom-up, design engineers were now presented with a CAD application that aids them in translating their engineering design into the digital information model that ultimately represents the end product that they are to generate. However, in order to do so, design engineers would need to carry out a considerable amount of what has become drafting work, in order to translate their work into this information model. Design engineers, however, are not supposed to be responsible for the drafting efforts that are to be executed in a project; that is strictly the responsibility of the draftspersons, as it comprises the majority of their job role, as they (the design engineers) are responsible for carrying out other design tasks, such as calculations, data analysis, and scenario simulations.

Meanwhile draftspersons were now presented with a CAD application that decreases some of the pure drafting work needs, but in return it requires them to take educated technical decisions in their drafting process, which is necessitated by the software. This implies that the job role of the draftspersons would require a decrease in the level of routine work that they are responsible for, which is strictly identified by the drafting job role being somewhat oblivious to the technical details and aspects that are being drafted. As was detailed, with the original design process, when using AutoCAD, the design engineer would be responsible to provide the draftsperson with sketches detailing the knowledge to be represented. However, with AutoCAD the draftsperson was not aware of the technical content that they were detailing in the drawings; neither did they need to be. This meant the job of the draftsperson was somewhat technically bland, and simultaneously demanded no technical knowledge on behalf of the draftsperson. With the introduction of the new CAD application, the draftspersons were now required to ‘know more’ in order for them to perform their job tasks effectively, and so this has necessitated further education in order to perform their job.

E. Comparing the Two CAD Applications

In table form, a simplified breakdown of the comparison of the two CAD software applications is provided below.

Table 2: Comparing the features and functionality of AutoCAD vs. Revit

Feature	**AutoCAD**	**Revit**
Coordination and Collaboration	Manual; plans must be checked and coordinated individually	Embedded; the model is coordinated in real-time
Drafting	Manual; drafting skills required	Semi-automated; design knowledge required
Flexibility	Rigid; usually requires redrafting	Relatively easy and automated
Conflict Detection	Manual; plans must be checked and coordinated individually	Embedded; the model is analyzed in real-time
Content Awareness	Content-agnostic	Content-driven

F. Summary

After collecting data on Alpha engineering design firm, we have analyzed the underlying information to better understand the new processes of work that are enacted in the firm. Furthermore, we also offered an overview of the two CAD applications, as well as a comparison that illustrates some of the most notable functional differences between the two applications. Therefore, we have now set the stage to move on to the next chapter to present the findings that emerged from the analysis of the interviews that were carried out.

In the following chapter we will be presenting the effects of the new technology on the organizational structure, i.e. job roles, and responsibility distributions of the members. A ‘generic’ core engineering design unit is the focus of our discussion.

CHAPTER VI

FINDINGS

We present our findings covering two primary activities: design and drafting. Within this paper, 'design' comprises of all work, tasks, and knowledge that are needed to complete technical/engineering aspects of work. 'Drafting' comprises of all work, tasks, and knowledge that are needed to complete the drafting part, which used to exclude technical work.

Based on the research methodology presented earlier, a generic framework of the work processes was mapped out for the design engineer and the draftsperson. The framework is generic in that it lacks details pertaining to a specific engineering field. This is due to the fact that the process, as a whole, is seen to be almost identical amongst most engineering trades. The differences that were noted in the data collection came down to very specific tasks that are characteristic to the system that is being designed. These will be discussed in further detail when presenting examples in the rest of this chapter.

The following sequence of events constitutes the tasks of the design engineer, when working on a project for which the team uses AutoCAD:

- Discusses with the project engineer the design concept to be used for the project, of the system to be implemented in the design.
- Identifies the system components required to design the system (creates a list with basic specifications).
- Develops a preliminary system plan (by-hand) to visualize the architecture of the system (based on the list and basic specs).

- Receives printed plans from the draftsperson.

- Sketches the system symbols of the system on the printed plans, in their corresponding locations, aligning the design concept (identified earlier) to the site plan. The printed plans are printed to-scale and therefore all measurements can be carried out on the plans with a ruler.

- Provides the draftsperson with the sketched plan, possibly giving minor directions in case of any special drafting requirements, imposed by technical details.

- Based on the preliminary sketches and the design concept, carries out calculations in order to refine the system specifications, and component quantities.

- Communicates and coordinates architectural requirements to architect(s).

- Communicates and coordinates mechanical, engineering, and plumbing requirements from/to other engineering working on the project.

- Continuously goes through a back-and-forth exchange with the draftsperson, of printed layouts where the engineer provides new details sketches and/or refinements to the design, in parallel with the coordination process with other engineering trades.

- Continuously updating calculations (if and when/where needed) in order to refine the designed system. These need to be continuously coordinated with the project engineer, as they need to update the system specification documents accordingly.

- Once the drafting process is finished, the engineer provides the draftsperson with the sheet frame, in order to prepare the sheets as per the project presentation direction; this information is as per the project's "work instruction", which is provided by the project manager.

- Once the final sheets (framed and coordinated layouts) are ready, the design engineer takes them from the draftsperson, and presents them to the project engineer for review. Any corrections are then taken back (by the design engineer) and given back to the draftsperson with the sketched corrections accordingly. This process repeats until the plans are error-free and ready for submission.

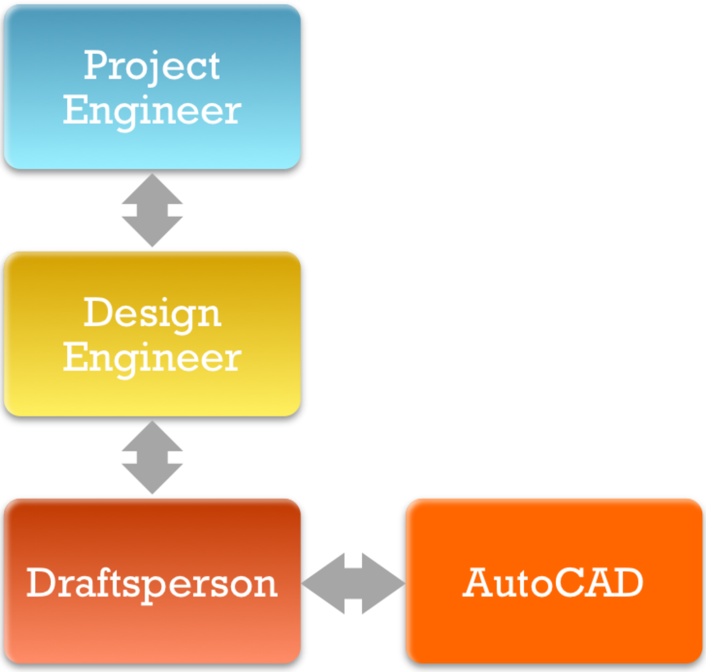

Figure 5. The project workflow when working with AutoCAD.

The following sequence of events constitutes the tasks of the design engineer, when working on a project for which the team uses Revit:

- Discusses with the project engineer the design concept to be used for the project, of the system to be implemented in the design.
- Identifies the system components required to design the system (creates a list with basic specifications).
- Develops a preliminary system plan (by-hand) to visualize the architecture of the network (based on list and basic specs).

- Creates the Revit project file, and all the families (sets of virtual representations of system components) to be used in the project.
- Begins working on the Revit model by placing "family components" of the system on the virtual model, in their corresponding locations, aligning the design concept (identified earlier) to the model.
- Continues this procedure while consistently coordinating with other trades, regarding their systems' and components' locations.
- Based on the preliminary design implemented, and the design concept, executes calculations in order to refine the system specifications, and component quantities.
- Communicates and coordinates architectural requirements to architect(s).
- Communicates and coordinates mechanical, engineering, and plumbing requirements from/to other engineering working on the project.
- Continuously updating calculations (if and when/where needed) in order to refine the designed system. These need to be continuously coordinated with the project engineer, as they need to update the specification documents accordingly.
- At this point the design model would have been developed enough that the design engineer begins to include more details in the model, such as wiring, or tagging, coordinating fixture heights according to the on-going coordination with other trades.
- Starts finalizing further characteristic details pertaining to system components, such as power requirements, and heat dissipation degrees.
- Once the design and drafting process is finished, the engineer provides the draftsperson with the sheet frame, in order to prepare the sheets as per the project presentation direction; this information is as per the project's "work instruction", which

is provided by the project manager; at this point the draftsperson takes over the Revit model to create the sheet layouts.

- Once the final sheets (framed layouts) are ready, the design engineer takes them from the draftsperson, and presents them to the project engineer for review. Any corrections are then taken back and worked on directly by the design engineer to carry out the corrections accordingly. This process repeats until the model is error-free and ready for submission.

- The design engineer then hands the model back to draftsperson in order to produce/export the final sheet layouts.

Comparing the above two lists of event sequences taken on by the design engineer, we are able to discern the change in technical knowledge required by the design engineer to do his work with the new software:

- Needs to determine more detailed system specifications at an early stage of the project in order to implement them correctly from the beginning.

- Needs to coordinate system components' specific locations, in real-time, with other trades in order to avoid "clashes".

- Using Revit to export system components quantities automatically (was previously a manual procedure by counting).

- Using Revit to ease the drafting process by automating some of the tasks that previously needed to be performed manually by drawing.

Doing a similar comparison, we are also able to discern the change in drafting knowledge required by the design engineer to do this new type of work:

- Needs to know how to use Revit to place the system components on the engineering model.

- Needs to know how to use Revit to modify system components characteristics, and attributes to confirm with the design and environmental requirements.
- Needs to learn how to draft routing pathways for system delivery (e.g. vents for an HVAC system, or cable trays for data network) and define their characteristics in Revit.
- Needs to know how to use Revit to modify routing pathways in order to adapt them to any layout and coordination changes.
- Needs to learn how to measure (on the digital plans) distances in order to make design decisions, due to systems distance (technical) limitations.

The following sequence of events constitutes the tasks of the draftsperson, when working on a project for which the team uses AutoCAD:

- Receives the architectural plans and prepares the design plans by linking (external references) them to the architectural base plans.
- Prints the plans and presents them to the design engineer.
- Receives the plans from the design engineer with sketches, and implements the sketched drafts onto the drawing file.
- Once finished with implementing the sketches provided by the design engineer, prints the new plans, and presents them to the engineer again, for further development; this procedure repeats a number of times until the design drawings mature enough.
- The draftsperson then awaits and receives the frames from the design

engineer and begins preparing the sheet layouts in line with the project presentation direction; the design engineer provides this information.

- Provides the design engineer with the printed final sheets (framed and coordinated layouts).

- Implements any corrections needed to be done based on the project engineer's communication with the design engineer; process is repeated until the sheets are error-free.

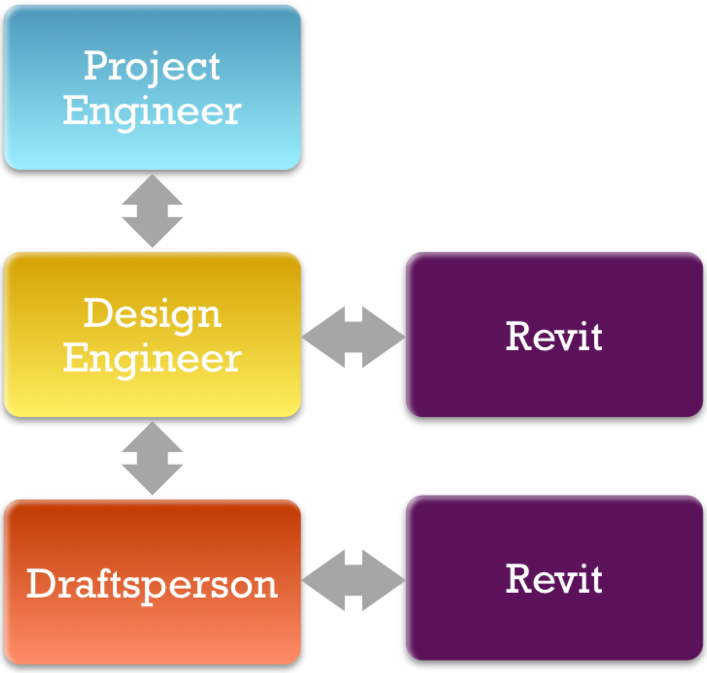

Figure 6. The project workflow when working with Revit.

The following sequence of events constitutes the tasks of the draftsperson, when working on a project for which the team uses Revit:

- May be responsible for refining or developing the visual representation (2D, or 3D) of Revit families of the system components.

- Receives the sheet frames and the model from the design engineer in order to prepare the sheet layouts in line with the project presentation direction; the design engineer provides this information.
- Once the final sheets (framed layouts) are ready they are printed and given to the design engineer for project engineer review.
- Once the model is finalized, it is given back to the draftsperson from the design engineer, in order for any final touch-up and clean-up work (if needed), as well as to produce/export the final sheet layouts.

Doing a similar comparison of the work of the draftsperson, we are able to deduce that there is little change in the technical knowledge required by the draftsperson to do this new type of work. Furthermore, we can also deduce that the change in drafting knowledge required by the draftsperson to do this new type of work as follows:

- Needs to know how to use Revit to prepare and produce sheet layouts.
- Needs to know how to use Revit to do some minor “cleanup” work (if needed, and where possible) to improve the presentation of the model.

The above comparisons clearly point to the procedures and tasks that are carried out by both a design engineer and a draftsperson throughout a generic project timeline. It is evident that design engineers are under pressure to adapt their knowledge pertaining to design tasks, as well as pertaining to drafting tasks. Draftspersons, on the other hand, only exhibit a change in the drafting knowledge required in order to work with Revit. It is also evident that the amount of work that is being performed by a design engineer has significantly increased, as they are now responsible to work directly on Revit, which is contrary to the case with AutoCAD, where the draftsperson was responsible for doing that. Accordingly it is also apparent that the amount of work that is being performed by a draftsperson has significantly decreased.

All else being equal, let us walk through an example, through which, we may be able to visualize this phenomenon. It is assumed that workload is defined and measured as the capacity of work to which a job role definition is fulfilled. Therefore, in the case of a balanced workload, each member of a team is performing all the tasks that they are responsible according to their corresponding job role. In the anomalous case where certain members take on tasks that are in excess of their job role definition, while other members in turn take on less work than their job role definition. We refer to this as an unbalanced work state. For example, a draftsperson's job role, as was defined, and without loss due to brevity, comprises of all tasks related to drafting. Analogously a design engineer's job role comprises of all tasks related to designing engineering systems. When each of these job roles are performed, and the workload is distributed accordingly to its corresponding personnel, we consider this to be a balanced work state (see Figure 7).

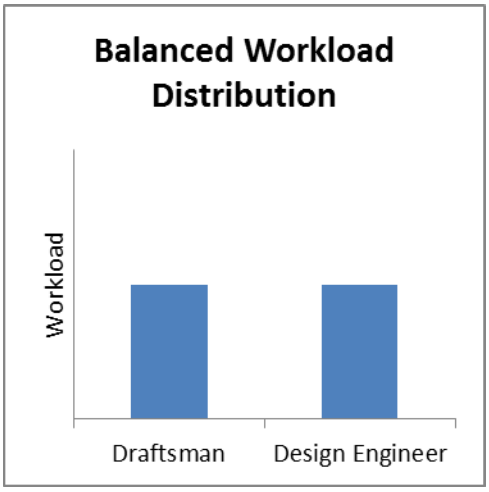

Figure 7. The balanced workload distribution between design engineers and draftspersons.

The opposite of this balanced work state is the unbalanced work state, is that the member (i.e. design engineers) is forced to produce at a level beyond that to which their job role definition is fulfilled, while other members (i.e. draftspersons) are forced to produce at a level that is below that to which their job role definition is fulfilled (see Figure 8).

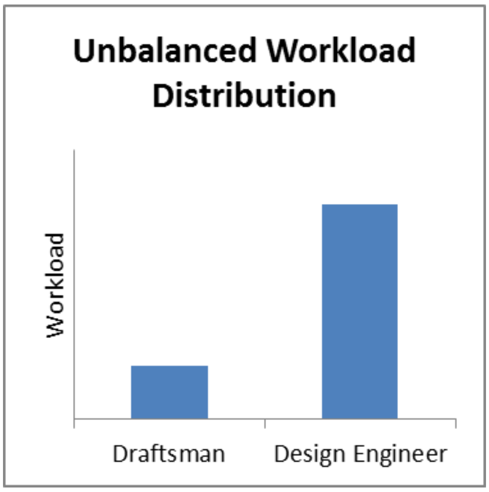

Figure 8. The unbalanced workload distribution between design engineers and draftspersons.

From all the changes that are brought about by introducing Revit into the workplace, in turn replacing AutoCAD, three patterns have emerged. These patterns pertain to the relationship between different factors and dimensions of the workplace, as well as the employees. These three patterns are (1) the nature of the work tasks relative to the required knowledge to perform those tasks, (2) the time-consumption differences per task based on the nature of the task, and (3) the level of 'role-stickiness' and how it relates to the level of technical knowledge of the tasks being executed.

A. Knowledge/Work Relationship Mixing

There is a relation between the nature of the work, and the knowledge requirement to carry out that work. The nature of the work is defined by the tasks that need to be carried out in order to do this work. The knowledge content is the type of know-how that is needed to carry out these tasks. In our case study, the tasks being carried out are either design tasks or drafting tasks. Accordingly, we compare the tasks that are required to do design work and drafting work in the two scenarios, with AutoCAD, and alternatively with Revit.

In the case of AutoCAD there was a one-to-one relation, where design tasks required design knowledge, and drafting tasks required drafting knowledge. However, with Revit the relation transforms into an 'ensemble'. There are now design-tasks that require design-knowledge, design-tasks that require drafting-knowledge, drafting-tasks that require design-knowledge, and drafting-tasks that require drafting-knowledge.

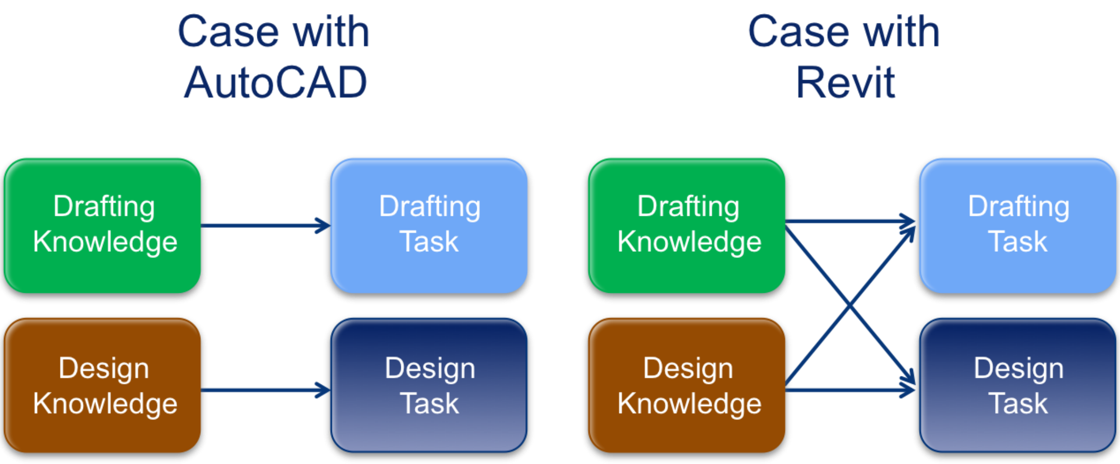

Figure 9. A visual comparison of the two cases with AutoCAD and Revit, illustrating the "knowledge/work relationship mixing" pattern.

We see that in the previous state with AutoCAD there was a clear boundary between design tasks and drafting tasks. This is mainly due to the one-to-one relation evident between the tasks and the knowledge required to fulfill these tasks. By way of the logic presented above, this implies a clear boundary between design work and drafting work.

After the move to Revit, the previous relation of tasks to knowledge requirement is changed. There is no longer a one-to-one relation between the nature of the tasks and the knowledge that is required to carry them out. Therefore, this brings about the new configuration where there are design tasks that require drafting knowledge or drafting tasks that require design knowledge. Relating this to the logic that was presented above, the relation between design work and drafting work and their corresponding knowledge requirements result in a combination of different knowledge types. Originally design work required design knowledge, and drafting work required drafting knowledge; these relations remain after the move to Revit. Now, in addition, design work requires drafting knowledge and drafting work requires design knowledge. This phenomenon has led to the need to up-skill draftspersons so that they need to have additional technical knowledge in order to do some design tasks that they were not previously responsible for.

1. Example: Drafting an Electric Circuit

An example is given of an electrical design engineer developing the electric circuitry for a design that he is responsible for. With AutoCAD the procedure for an electrical design engineer was to “do the engineering work, then […] print the layout on a paper, then […] do the wiring or the sketches by-hand and […] hand it to a draftsperson, and the draftsperson does it himself". Through this process, the design engineer does not interact with the drafting software, nor does he work on the visual implementation of the design beyond the sketch that he provides the draftsperson with. Here we see the clear boundary between the design work being carried out by the design engineer, and the drafting work being carried out by the draftsperson. The engineer is responsible for the technical know-how of designing an electrical circuit, and roughly representing it on a sketch. Conversely, the draftsperson is responsible for the drafting know-how of implementing the sketch of the electrical circuit, and "drafting it as per [Alpha's company] drawing standards".

In the case of using Revit, the process changes. With AutoCAD, the draftsperson would work with the software, while the engineer would supply sketches. With Revit, the design engineer is now responsible to work on Revit directly; the process of sketching and 'handing the sketches to the draftsperson' has been eliminated. The electrical design engineer explains that "Revit actually does the wiring […]; [but] you still have to specify what luminaire or electrical fixture you have to put on the same circuit. So you just tell Revit that I want this, this, and this fixture to be on the same circuit, and you specify which electrical panel you want to use, and Revit will go ahead and do the wiring". Observing this scenario one highlights the fact that the design engineer is now implementing the drafting task in order to produce the final engineering model.

What changed here is the character of drafting as it is defined in each of the two scenarios. With AutoCAD drafting implied that the person drafting would have to draw lines, circles, and arcs in order to represent a given model. In the case of Revit however, drafting is carried out based on the 'object' of the task that needs to be executed. Our example here highlights how drafting with Revit for an electrical engineer has transformed drawings lines and circles, to selecting the electrical fixtures that the designer wants on the same circuit, and having Revit do the rest. This may be characterized as a 'deskilling' phenomenon. The actual task of drafting in this case is no longer a matter of drawing, but rather a matter of taking a set of technical design decisions. The following table summarizes the two different processes of producing a design of an electric circuit; in the case of AutoCAD and in the case of Revit.

Table 3: Summarizing knowledge/work relationship mixing example of drafting an electric circuit, comparing the case when working with AutoCAD vs. Revit.

Case with AutoCAD	**Case with Revit**
Design engineer develops the technical data required to implement the design.	Design engineer develops the technical data required to implement the design.
Design engineer develops sketches the required model out by-hand.	Design engineer selects the electrical fixtures per electrical circuit, on the software directly.
Design engineer hands the sketches and drawings to the draftsperson.	Revit presents the design engineer with a model of the inputs that he set in the previous step.
The draftsperson implements these sketches on AutoCAD to provide a final digital model.	

This example highlights the usage of Revit by an electrical design engineer performing the design task of assigning electrical fixtures to an electric circuit. The output of this task is a designed model of an electric circuit, accumulating a number of electrical fixtures, and connecting them to an electrical panel. The main element to be noted is the fact that the design engineer is interacting directly with the modeling application in order to produce an engineering model. In contrast with AutoCAD, the same engineer mentions that "we usually do the engineering work, then we print the layout on a paper, then we do the wiring or the sketches by-hand and you hand it to a draftsperson, and the draftsperson does it himself".

Referring back to the phenomenon being illustrated, this scenario exemplifies how the relation between work and its knowledge content have changed. The drafting task of representing an electrical circuit used to be carried out by drawing the wiring of the actual circuits. Now (with Revit) it is executed by a set of technical design decisions. The drafting work, which is accomplished by drafting tasks, is being implemented by way of technical decisions that are based on design knowledge.

2. *Example: Designing a Data Network Cable Tray Route*

In this example a telecommunications design engineer is implementing a cable tray route for a design of a data network that he is responsible for. With the previous setting of when using AutoCAD the procedure for a telecommunications design engineer is similar to the procedure highlighted in the previous example. The engineer is "responsible for sketching the route by hand and then [he gives] it to [the] draftsperson so he can draw it on AutoCAD". Identical to other design engineers in other trades, the telecom engineer is not responsible for using the drafting software to represent his design. He does not work on the visual implementation; he only provides the draftsperson with a sketch indicating the route and width of the cable tray. Once again here we see a clear delineation between design work by the design engineer, and drafting work by the draftsperson. The engineer is responsible for the technical knowledge of designing a cable tray route, and creating a sketch to represent it. In turn, the draftsperson is responsible for the drafting knowledge to be able to transform the sketch of the cable tray route into “a digital and accurate visual representation of how it is supposed to really look”.

The drafting details in this example are more specific, as the draftsperson is responsible for the true visual representation of a cable tray. These details are considered as “drawing standards”, claims a draftsperson that develops such drawings. For example there are certain minor drafting details such as “T junctions” and corners that need to be represented accurately. The design engineer elaborates further: “T junctions need to be chamfered and corners require a certain radius of curvature as per the standard design code”, the design engineer goes on to state, “if the cable trays are not drawn accurately, then the design drawings would be misleading for the contractor”. Therefore it is evident that the actual visual representation of the cable tray is an essential attribute to the final engineering model.

Given this information, and moving on to the case of using Revit, the process changes qualitatively. As was the case with the electrical engineer, with AutoCAD, the draftsperson would work with the software, while the telecom engineer would supply the draftsperson with sketches. These sketches would be accompanied with technical details, such as the cable tray width, and the radius of curvature of the cable tray. These technical details affect the visual representation of the cable tray, which affects the interpretation of the final engineering model. Once the shift to Revit took place, the design engineer is now responsible to work on modeling application directly, bypassing the task of sketching the design and giving it to the draftsperson. This also implies that the engineer designs and draws the cable tray simultaneously. A two-stage procedure is now combined into one. The telecommunications design engineer states: “with Revit I directly input the technical details of the cable tray, and since Revit is smart enough to understand them, I then draw it by simply pointing and clicking on the path that I want it to take, according to my design, and Revit takes care of the rest”. He also goes on to say: “if I want to change anything, in the design, I can do it right then and there, since I’m working on Revit directly”. We see how in this scenario the design tasks have become unified with drafting tasks. The design engineer has to “draw” the cable tray in order to visually represent the design that he develops while concurrently attempting multiple design approaches, in order to produce the final engineering model.

The key difference in this example is the knowledge required by both Revit, and the engineer, to execute the work of designing a cable tray route. The first difference is that Revit is “smart enough”, as mentioned by the design engineer above, to “understand” the technical attributes of a cable tray. AutoCAD on the other hand is completely oblivious to the content of the drawings, other than the fact that they contain lines, arcs, and circles. The second difference is that the tasks of drawing have changed in form and in turn absorbed the design tasks into them. Previously, with AutoCAD, the draftsperson would draw the lines and the arcs that visually represent the cable tray based on the engineer’s sketch. Any changes to the design would have to go through another iteration of a back-and-forth exchange of data between the engineer and the draftsperson. With Revit, the design engineer merely “point[s] and click[s]” on the path that he needs the cable tray to take, and Revit “takes care of the rest”. Meanwhile, the decisions made can be changed concurrently, without the need to go back-and-forth. Here we see the potential deskilling phenomenon of the draftsperson, taking place. The actual task of designing in this case is not a matter of sketching pathways and exchanging data along the way, but rather a matter of pointing and clicking the required path and altering it accordingly. The following table summarizes the two different processes of producing a design of an electric circuit; in the case of AutoCAD and in the case of Revit.

Table 4: Summarizing knowledge/work relationship mixing example of designing a data network cable tray route, comparing the case when working with AutoCAD vs. Revit.

Case with AutoCAD	**Case with Revit**
Design engineer develops the technical data required to implement the design.	Design engineer develops the technical data required to implement the design.
Design engineer develops sketches the required model out by-hand.	Design engineer inputs the technical attributes of a cable tray into the software directly.
Design engineer hands the sketches and drawings to the draftsperson. Along with technical details that affect the drawing.	The design engineer selects the path of the cable tray, by pointing and clicking his way through, while Revit draws the design.
The draftsperson implements these sketches on AutoCAD to provide a final digital model.	Any changes to the design are carried out directly by the engineer.
Any changes to the design would require another iteration of data exchange between the engineer and the draftsperson.	

This example highlights the usage of Revit by a telecommunications design engineer designing a cable tray route as a data network cables pathway. Here we see once again, the design engineer interacting directly with the modeling application, to produce an engineering model. This contrasts with the case of using AutoCAD, where the engineer was only responsible for the design tasks required to complete the work. Then he would provide the draftsperson with all the details that he requires in order execute his drafting tasks.

Referring back to the phenomenon being illustrated, this scenario exemplifies how the relation between work and its required knowledge has changed once again. The work of designing a data network cable tray route would be carried out by determining corresponding technical details, and sketching them, then having them drawn by a draftsperson. Now it is executed by a set of technical design decisions that are carried out as the engineer draws the cable tray. The design work, which is accomplished through design tasks, is being implemented by way of drawing, which is based on drafting knowledge.

B. Tasks Quantity, Frequency and Period, by Task Type

We present a relation between the duration of time that a task consumes, and the technical knowledge requirements for that task. This is based on the previous definition of design work (and design tasks), and drafting work (drafting tasks). A comparison of the roles of the design engineer and the draftsperson is provided, relative to their work tasks and the time that these tasks consume.

Design knowledge and drafting knowledge are very well defined, and distinct from one another. The comparison lists at the beginning of this chapter provide an illustration of the process of creating and developing a design. It also outlines the tasks that are carried out be each employee to perform their job responsibilities. Design engineers are responsible for numerous tasks that are related to the technical design aspects of a system. Engineers need to translate design concepts into a functioning engineering system design. After which, they begin sketching engineering system components that are to be used to visually represent the system design. Once they have a working preliminary concept, they carry out calculations to validate, refine, and further develop the system sketch, making it more and more mature. They are also then responsible to carry out coordination tasks with other trades, so as to ensure that the design that is being carried out synergizes with the rest of the project. Simultaneously, they are involved in continuous dialogue with the draftsperson continuously to develop, and update the plans in order to ensure that all coordination efforts and technical refinements are implemented, and done so correctly. Also, they need to work directly with their supervising project engineer to make sure that the designed system is aligned with all project requirements, as per project contracts. These are tasks that need a high level of technical knowledge. However, each task individually does not consume a large amount of time to execute. Draftspersons on the other hand are responsible for very few tasks that are related to the visual representation of a system, and that are time consuming to carry out. They are responsible for drawing the sketches that they are provided, while consistently developing them and refining them, as per the design engineer's instruction. During the drawings process, they are responsible to add tags to the design, which indicates further details regarding the system, also as per the design engineer's instruction. And finally, they are responsible for developing the visual layout of the sheets that will be plotted and presented to the client.

A clear difference is seen between the numbers of tasks that each employee is responsible for. A design engineer is responsible for carrying out numerous tasks, compared to the few tasks that a draftsperson is responsible for. However, the design engineer and the draftsperson work in parallel to one another. Therefore it is apparent that while design tasks are many and require a high level of technical proficiency, they each consume a short period of time to be executed. Conversely, drafting tasks are few and require a low level of technical proficiency, however, they each consume a much longer period of time to be executed.

C. Role/Knowledge Stickiness and Mobility

There is a relation between the degree of technical knowledge and the task specialization that a given employee can perform. We define the degree of technicality by outlining the nature of the task that is being performed. In a broad sense, a design task is considered to be highly 'technical', while a drafting task is considered to be rather 'nontechnical'. From this logic we deduce that design knowledge is highly technical, while drafting knowledge is considered nontechnical.

Given the two initial types of work, the inverse of the level of technicality of the work, provided a degree of 'mobility'. This means that since an engineer is responsible for highly technical work they can only perform the work that they were trained for. This introduces the notion of stickiness. Therefore if we assume that there is a need to reposition an engineer from one department (engineering trade) to another, then this would require a high level of reskilling. This reskilling would be essential in order to have the engineer acquire the technical knowledge to perform the required design tasks. Therefore we can see that for the engineer, there is high level of role/knowledge stickiness. In contrast a draftsperson was highly mobile given the nontechnical nature of his work. In essence a draftsperson is only responsible for taking sketches and details from a design engineer, and drawing them in a digital form.

Breaking down this drawing task further, it is defined as drawing combinations of lines, arcs, and circles to represent engineering sketches in a digital form. The content of the drawing does not require any prior knowledge needs on the draftsperson, as they do not need to be aware of the technical definition of the systems. Due to the nontechnical nature of the drafting work, a draftsperson could easily adapt to drawing systems of one engineering trade versus another engineering trade. Therefore we can see that for the draftsperson, there is a low level of role/knowledge stickiness. Therefore, and in contrast to a design engineer, a draftsperson is highly mobile given the low level of technicality in their work. Thus, there would be virtually no need to reskill the draftsperson, since they would be using the same skills in each of the engineering trade, just to draw different things.

A change was then brought about when moving employees from working on AutoCAD to working on Revit. This change imposed an increase in the technical knowledge requirement for the draftspersons. As there was a clear boundary between design work and drafting work, in the case with AutoCAD, the distinction was not as clear in the case with Revit. The level of technicality of the knowledge required to perform the underlying tasks is related to the nature of the tasks. With AutoCAD there was a one-to-one relation between performing tasks and the knowledge required to perform them. With Revit, as was demonstrated earlier, a recombination was brought about whereby design tasks now require drafting knowledge and drafting tasks now require design knowledge. The outcome of this phenomenon led to a need to up-skill the draftspersons. Management appears to have come to this conclusion in order to restore a form of balance in the workload distribution between the design engineers and the draftspersons. One manager explains that they “had to teach the draftspersons some basic engineering skills so that they could start using Revit, and take that load off the design engineers, who are busy enough as it is". This task of up-skilling the draftspersons, inevitably meant that they would increase the level of technicality of their knowledge. With this increased level of knowledge they would be able to perform "basic" design tasks.

Seeing the change in the level of technical knowledge of draftspersons, we experience an increase in their degree of their role/knowledge stickiness, and hence their ability to be mobile decreases. Following the logic presented, a low level of technical knowledge implies a high level of mobility, while a high level of technical knowledge implies a low level of (or almost no) mobility. Up-skilling the draftspersons in order for them to be capable of using Revit meant two things. First, they had to train on using this new CAD application so they can perform their original task of drafting at a level of proficiency that is at least equivalent to that of using AutoCAD. Second, they had to acquire some technical knowledge pertaining to the systems that they would be helping the engineer to design. Therefore, draftspersons are now becoming more technically specialized in the work that they perform. The level of technical specialization in some cases is as finely defined as assigning a certain draftsperson to a single system, corresponding to a specific engineering trade. For example, in the mechanical engineering department there are engineers that are responsible for designing plumbing systems, while others are responsible for designing heating, ventilation, and air conditioning (HVAC) systems. As a result of this a draftsperson that works in the mechanical engineering department, has been up-skilled to work specifically on plumbing, HVAC, or any of the other mechanical engineering systems. Therefore, the role/knowledge stickiness factor for this draftsperson has increased considerably. This same draftsperson cannot easily move from working with Revit on plumbing systems, to working with Revit on HVAC systems, unless given the technical knowledge to do so.

It is evident that there appears to be a negative relation between the level of technical knowledge and the ability to move an employee from performing one category of work to another. In our research, this phenomenon was evident via the process of up-skilling draftspersons. The up-skilling was seen as an essential step to provide the draftspersons with the knowledge that they need in order to fulfill their job responsibilities accordingly. Also it was required, as the design engineers had become overloaded due to having to take on the extra task of working on Revit, in addition to the work that they are originally responsible for.

1. *Example: Moving a Mechanical Engineering Draftsperson from Plumbing to HVAC*

While in the midst of an interview with the manager of the mechanical engineering department, we were disrupted by a draftsperson of the department. The design engineer that he was assigned to was responsible for designing the HVAC system on the project that he was working on. Therefore the work that was being assigned to this specific draftsperson was to work with Revit on the HVAC system for the project. The draftsperson complained that he does not know "how to use Revit to work on HVAC". He went on to explain, "the same way I can't do the work of an electrical engineer, because I don't know electrical systems, I can't work on HVAC because I don't know HVAC. I only trained on plumbing, so I can do plumbing". This scenario exemplified the notion of role-knowledge stickiness experienced by the draftsperson as a result of up-skilling (by having him acquire more technical knowledge), rendering him more technically apt, as well as specialized, in a given technical field. A comparison of the two cases (of Revit vs. AutoCAD) is summarized in the following table.

Table 5: Summarizing role/knowledge stickiness example, comparing the case when working with AutoCAD vs. Revit.

Case with AutoCAD	**Case with Revit**
Design engineers have a high level of technical knowledge and are restricted to the bounds of their technical knowledge.	Design engineers still have a high level of technical knowledge and are restricted to the bounds of their technical knowledge.
Draftspersons have a low level of technical knowledge and are free to work in any department.	Draftspersons acquire a higher level of technical knowledge than before, and now they are restricted to the bounds of their technical knowledge as well.

D. Summary

Based on the findings of this research, three patterns emerge from the data analysis. First, there was a recombination effect in the knowledge requirements between design work and drafting work. With the introduction of the new CAD software, an ensemble-like combination of interdependencies is formed between the knowledge requirements to execute tasks. There was also a pattern of skilling, whether it is deskilling, reskilling or up-skilling. The new technology effectively automated certain tasks, leading to a deskilling effect, and in turn imposed more knowledge requirements on draftspersons, thus required the draftspersons to be up-skilled. Finally, we identified a relation between the level of technical knowledge and the level of role-knowledge stickiness that is apparent. As an outcome of this there is a decreased level of mobility. Now managers are no longer able to move draftspersons around at will, due to this new constraint, and furthermore they need to account for the fact that different draftspersons need to be multi-skilled, in order to be able to work multiple engineering systems.

The resulting process model of this process is illustrated in the following figure (see Figure 10), identifying the key knowledge change effects that take place at every stage of the process.

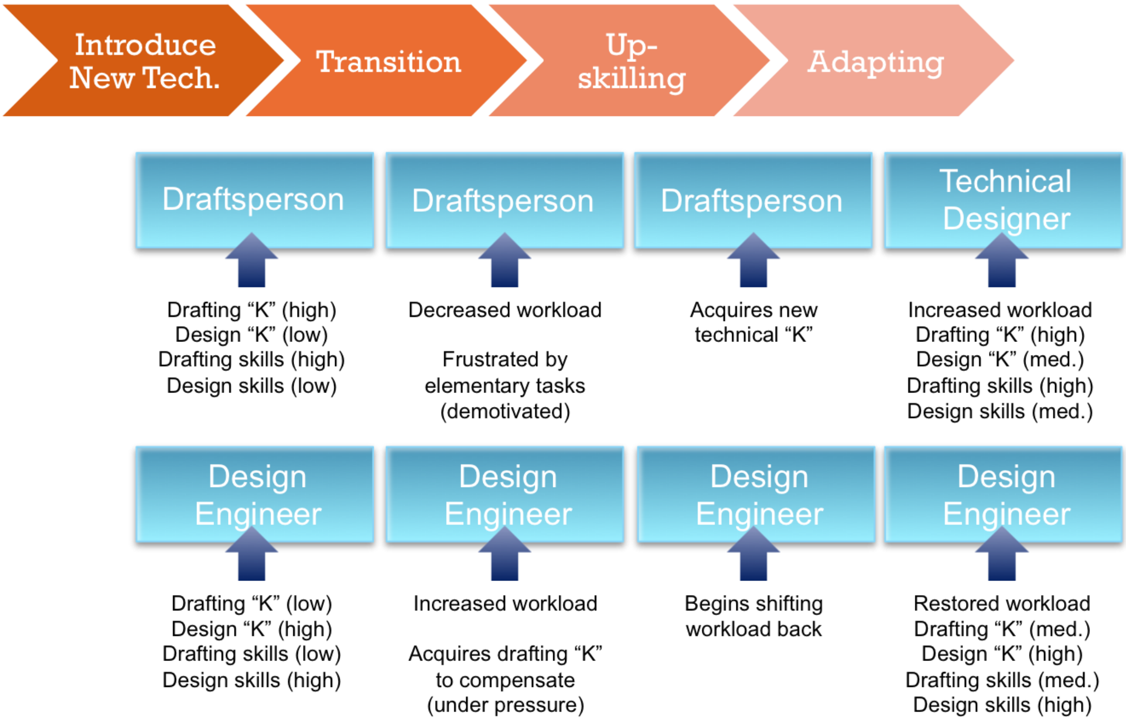

Figure 10. The process timeline that was observed from the time of introducing the new tech., up until the phase of adaptation.

CHAPTER VII

DISCUSSION

A. Case Study Contribution

The research presented in this paper deals with the introduction of a new technology into a firm's core operational processes. The research moves forward to elaborate how this new technology effectively changes the way work is practically executed in the company. This affects how employees carry out the tasks needed to do their jobs, as well as how these tasks, in some cases, are redefined by the use of this new software, and finally how such changes even ultimately influence the organizational structure of the firm within its professional/technical ranks. The primary contribution of this paper is the exploration and identification of the changes brought about by introducing new CAD technology into an Alpha engineering design firm. Prior research has rarely dealt with the effects that technology imposes on the way work is done on a job role level (rarely addressed since Barley 1986, 1990). From the data acquired for this research we were able to illustrate real-world examples of *how* technology is effectively bringing about such changes.

Previous research rarely focuses on the knowledge content of work, especially for members in the engineering construction industry. More specifically, the knowledge content of day-to-day work of engineers and draftspersons is rare as an entrée to study the effective organizational structure changes that are brought about by new technologies.

Most of the previous works focus on the steady-state and the after-effects of process changes. This "black boxes" the process changes and makes them opaque. In contrast, in this research we specifically focused on the process changes, and not the steady-state after-effects. Studying these changes up close contributes to our understanding of how knowledge change, and knowledge work, change over time, and interact to produce a new configuration of roles and work in an organization.

The changes that we studied, which were instigated by a technology change from one technology to another technology, affected the knowledge contents of the work roles directly, and thus allowed us to explore how the micro-processes of change evolve and solidify in the organizational structures (role-based relational structures). By focusing on practice-based, on the ground, and day-to-day nature of work, we have produced a fine-grained understanding of the phenomenon that has been largely absent from prior research.

In summary, the changes that emerge from the data of the given case study comprise of three main patterns. First, the apparent recombination in the types of knowledge required to execute different work tasks, such as design tasks versus drafting tasks. Second, the deskilling and up-skilling effects that this has had on the draftspersons in the firm, as a result of the increased knowledge demand required from them to do their work. After the job task execution methods were modified, and the new CAD supplanted the task of drafting, the draftsperson was effectively deskilled in the short term. This evidently forced them to acquire new (technical) knowledge to be able to retake on the job tasks that they are responsible for; effectively, this redefined their job roles in the firm. Third, and as an outcome of the up-skilling pattern identified, draftspersons experienced a much higher level of knowledge/role stickiness, which essentially decreased their mobility in the firm. The quantity of tasks that a draftsperson could undertake previously, due their low level of technical knowledge, was much higher than after being up-skilled.

These observations provide reason for management of firms to further investigate the introduction of new technologies into the firm's operational processes prior to their adoption. Managers need not just consider the "linear" and expected/intended operational outputs that may result from such technology introductions (e.g. increasing operational effectiveness). Instead they should also account for the potential knowledge work changes and requirements that may result from them. Through this, managers can become aware of such potential consequences and thus improve the choices made in adopting new technologies, or at least be aware and cautious of the potential of such phenomena, taking place. A key learning of this research is that it managed to move beyond the clichés of the knowledge society and knowledge economy in a way that is otherwise totally inaccessible to research, focusing and de-black boxing *how* knowledge work is transforming engineering and drafting professions.

B. Limitations and Further Research

This paper is constrained by certain limitations that may be tackled in further research. First, and foremost, the case's context of the construction section in a Middle Eastern firm. This contextual situation can be relaxed by selecting cases in other industries and regions.

Second, this paper is based on the outcomes of twelve interviews carried out with employees from the two engineering departments, in a single firm. To examine this phenomenon further, it may be advised to consider carrying out the research on a wider scope of interviewees. Beginning with employees from other departments in the firms, and extending to other firms in the same sector in the region.

Third, further research can cover the macro effects that take place in organizations, when introducing new technologies. It is recommended to include external macro influences, such as trends in technology adoption among AEC firms.

Fourth, the research indicates that there are some feedback effects by the pressures of adopting the new technology on the educational requirements of new hires. Further studies can be carried out to examine the societal trends and educational program developments that may result from such pressures.

Fifth, incidents from the research gave indications of other elements to study, such as the motivation of the employees in the organization when they were faced with these changes. Further parallel studies can be conducted to study the interactions between elements of job enlargement, and job enrichment, with the transition to new technologies, along with the increased technical knowledge requirements, and the motivational impact (positive and/or negative) that this may have on employees.

Sixth, further studies can be carried out to develop a predictive framework that could aid managers in foreseeing sociotechnical implications that new technologies could have on their firms. Such a framework could provide powerful insight for managers to enhance their ability to deploy new platforms, and adopt new technologies while decreasing the conflicts that may take place.

CHAPTER VIII

CONCLUSION

In this research we addressed a gap found in previous research pertaining to organization-technology change. This organization-technology change takes place as organizations transitions from one work technology configuration to another. An exploratory case study research was carried out, where we analyzed how the role and knowledge content of engineers and technicians at Alpha Middle Eastern Engineering (a major regional firm) change, as they transitioned from one CAD technology (AutoCAD) to another (Revit) in their drafting and design practices.

In light of the attributes that are inherent to each of the two software applications (AutoCAD being of a more traditional structure consisting of points, lines and polygons while Revit being of a more object-oriented structure consisting of design objects; e.g., doors, junction boxes, circuits, roofs, etc.), the analysis reveals three distinctive patterns of knowledge content and role change that take place due to the transition: knowledge mixing; task/work load change; and role-knowledge-stickiness.

The pattern of knowledge mixing takes place between the tasks and roles of the engineers and the draftspersons, and their corresponding knowledge requirements. As a result the engineers appeared to have taken on to do some of the tasks that previously were the responsibility of the draftspersons, while draftspersons were expected to take on some of the tasks that the engineer used to be responsible for. Since these tasks however implied a need for technical engineering knowledge the draftspersons could not take them on. This left the engineers in an overloaded state, having to take on more work tasks that pertain to both drafting and engineering work, while the draftspersons were left with very little to do.

An emerging pattern resulted from this imbalance, which was that the task/work load of engineers had increased while the draftspersons' task/work load had decreased. This was not only observed trivially by the number of tasks assigned, but also by the nature of these tasks. Drafting tasks while few, require long periods of time, due to their nature as mundane, repetitive, and technically trifling tasks. And since these tasks were dumped onto the engineers, it left the draftspersons with very little to do, other than what was referred to as "left-over work". As an outcome, organizational policies were put in place to have the draftspersons upskilled so they may acquire the required technical engineering knowledge to carry out the new tasks presented by the introduction of Revit. The upskilling of draftspersons eventually restored the balance of work as they were able to take on more of the work that they used to do.

The third pattern deals with the increased role-knowledge-stickiness to the draftspersons' practices that resulted from their upskilling. The analysis of the case showed us that technical knowledge is acute in nature, in that it narrows the scope, or breadth, of work that a draftsperson could take on. Before transitioning to Revit, a draftsperson could have been assigned different projects and systems very easily, since their know-how was broad (i.e. not technically specific); it was concerned with manipulating points, lines and polygons. Subsequently, with the introduction of Revit the knowledge content of their work increased. An example was given to illustrate how a draftsperson that was upskilled with the technical knowledge of how HVAC systems work, did not have the 'freedom' to work with plumbing systems, since they did not have the technical knowledge for plumbing system, even though both systems fall under the scope of the same engineering department.

These patterns that emerge in the analysis, elegantly illustrate how the knowledge content changes on the ground, are emerging for both engineers and draftspersons by the introduction of new technology. This positions this research as one of the first, and of the few, real-world accounts of the on-the-ground day-to-day practices that take place in a Middle Eastern engineering firm, which exemplifies prior higher-level research that covers topics of organization-technology change and its effects on professional role changes that take place as organizations adopt new technology configurations into their operational processes.

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