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Assessing the Parametric Building Model Capabilities in Minimizing Change Orders

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ASSESSING THE PARAMETRIC BUILDING MODEL

CAPABILITIES

IN MINIMIZING CHANGE ORDERS

by

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Abstract

Design changes during construction, which are typical in most projects, lead to increased cost, loss of productivity and delays. These changes are usually due to approved scope changes or due to design errors and omissions (E&Os) found in the construction documents. Errors and omissions are typically manifested in terms of incorrect or inconsistent dimensions and layouts in the construction documents, or by the lack of timely and correct information that it is needed to build the project or to meet the code requirements. Among others, E&Os are usually caused by poor coordination and communication among the many parties involved in the design process.

The objective of this research is to explore the extent to which change orders resulting from errors and omissions in the design documents are caused by poor coordination and communications, and to determine the extent to which the use of the concept of the 3D parametric building model can be used to minimize or eliminate E&Os, hence minimizes total change orders.

The concept of the 3D parametric building model has been implemented in commercial software using object-oriented technology. It creates a centralized database storing all the information about the design components as well as their interrelationships. Thus, whatever change is made is consistently propagated to the entire design object.

The research was conducted through reviewing of the literature, a case study and a web-based survey among design professionals.

The study revealed that 35% of E&Os are primarily due to poor coordination and that the use of 3D parametric building model has a significant impact on productivity and on

improving the coordination of the design process. This model shows promising results in helping to minimize errors and omissions in the design documents.

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"To Allah, thanks for giving me the hope and strength to complete this work"

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1 INTRODUCTION

1.1 Background

1.1.1 Change orders

A change order (CO) is an action that specifies and justifies a change to the scope of a construction contract that alters the original time of completion or the project total cost, or both. It is also defined by the Construction Industry Institute (CII) as: “A change is any modification to the contractual guidance provided to the contractor by the owner, owner’s agent or design engineer. The contractual guidance comes to the contractor in the form of a contract package at which he/she uses it as a basis for the bid or the proposal. Change orders are typically due to one or more of the following reasons: (Hegazy et al., 2001)

- Subsurface conditions are different than those identified in the contract documents.
- Change in the regulatory legislations or code after the contract was awarded.
- Changes of scope during construction due to owner, owner’s agent or design engineer new or modified requirements.
- Correction of design errors and omissions.
- Availability of materials and equipments.
- Value Engineering proposals.

This research focuses on design related change orders, especially, those resulting from errors and omissions found on the design documents.

1.1.2 Design related Change Orders

Design related change orders are very typical in construction projects. These may be originated by the owner, the owner's agent, the contractor, or the design engineer. Owner changes are typically due to changes in the original scope of the functional or maintenance requirements for the project. The contractor might originate some change orders when design errors or omissions are discovered in the contract documents after the contract has been awarded. The design engineer might initiate some changes due to his/her inadequate knowledge of the existing conditions at project sites, design errors and omissions. Sometimes, Value Engineering studies conducted after construction has started suggest changes to the original design that may need a change order.

1.1.3 Change Orders due to design errors and omissions

Design errors and omissions (E&Os) are typically found in construction documents. E&Os are usually manifested in terms of incorrect or inconsistent dimensions and layouts in the construction documents, spatial interferences, or by the lack of timely and correct information that it is needed to build the project or to meet the code These errors and omissions are usually due to the designer's insufficient or poor knowledge of the construction process, or they might happen by implementing some changes in a specific area without proper assessment of the consequences of these changes. Another reason for design errors and omissions is inadequate communication of design information among the various design parties due to the poor coordination procedures. In most cases, due to a fragmented process in which design responsibilities of the project are assigned to different specialists, the designer who initiates a change might record this change in one document but may forget to reflect it in another. Besides, he/she might fail to communicate this piece of information to the other parties involved in the design, because this designer may be unaware that the other disciplines can be affected. Therefore, when a change in the design takes place all design documents should be updated properly. To ensure the integrity of the design, and to avoid further changes, these changes should be properly and timely communicated among the various trades and consultants involved in the project, or else E&Os would result. Consequently, change orders will be issued to correct them, which will ultimately cause cost and schedule overruns.

1.2 Methods of measuring and quantifying the impact of change orders

1.2.1 CII Methodology

The Construction Industry Institute (www.construction-institute.org) has conducted some research and published several reports dealing with changes in construction. Early publications discussed the impact of changes on construction cost and schedule and how these can increase the project cost due to some combination of the following: (CII Publication 6-10, 1990)

- Productivity degradation.
- Delays.
- Equipment and labor spent in tearing out completed work.
- Materials wasted in rework.
- Nonproductive periods during the redirection of work.
- Recovery scheduling.
- Equipment standby costs.

CII research gives some recommendations to improve the change process and /or minimize the adverse effects of changes. Most of these recommendations were directed to the owner showing how he/she can discourage the introduction of changes during the project life and minimizing the claims that might arise by:

- Including a certain contract clause to establish the mechanisms and procedures for administrating changes.
- Freezing the project scope as early as possible in the design process.
- Continuing a strong constructability program after the baseline scope and estimate to reduce the potential for changes.
- Reviewing and authorizing the proposed changes through a structured scope and change control program.
- Specifying in the contract documents that float is jointly owned, but responsibly shared with the contractor to accommodate changes.

The emphasis of the recommendations on this research was to measure the quantitative impact of the project change, (CII Publication 43-2, 1993). This research concludes that a significant correlation exists between the proportional amount of change on a project and labor productivity, both in design and construction phases. It states that the decline in the overall productivity due to the environment of excessive changes can alter the cost/benefit evaluation of potential changes and should be taken into account in project decision-making. The research recommends that project management should track the expected amount of change over time as a tool in assisting decisions concerning timing and/or organization of change implementation. This can be done by measuring the following relationships during the course of the project:

- Overall project change ratio and productivity, both in engineering and construction.
- The ratio of scope change work to the original scope work, by craft, expected to be experienced in future periods in order to predict or minimize productivity declines in periods of high change work.
- The ratio of total dollars in changes to material dollars as a measure of the implementation efficiency of changes over time.

The CII conducted a more recent research study on quantifying the cumulative impact of change orders for electrical and mechanical contractors (CII Publication, Research summary 158-1, 2000). This research provided a quantitative method for both owners and contractors to determine if change has impacted a project, and to provide a model for determining the probable magnitude of that impact on labor efficiency, especially in labor-intensive fields such as mechanical and electrical construction. In order to achieve their objective, the research team developed a questionnaire for contractors to provide data about projects that have been influenced by change orders and to determine whether these projects were “on budget” or “over budget”. These projects then were investigated based purely on work-hours and not by cost (dollars) because work-hours are directly comparable. Dollars can add complexity for a number of reasons, among them pay scale, premium time differentials, and material costs. In addition to the questionnaire, actual and estimated manpower-loading curves or weekly labor hours were requested for each project along with the change order log. After that the team developed a list of the influencing factors that could lead to change orders impact. They applied logistic regression techniques to test all these factors and to develop a model that could predict the probability that a project will be affected by change orders. These factors (shown in Table 1-1) were grouped by degree of impact and whether they were pre-award or post-award consideration.

Table 1-1 Factors that influence change order impact

(CII Publication, Research summary 158-1, October 2000)

Pre- Award Factors	Post - Award Factors
High Impact	
Project Size	Percent of Change
Estimated manpower loading	Timing of change
Quality of estimate	Quality of change
Bid document rating	Quality of preplanning
Schedule-driven project	Materials management
Renovation work	Schedule compression
Percent design complete	Unknown conditions
Operating unit	Lead time
	Allowance for extension
	Stacking of trades
	Effectiveness of team
Medium Impact	
Original duration	Tools and equipment
Type of Project	Availability of manpower
On-Site project management	Weather
Cost driven project	Project control management
Public or private	Materials handling constraint
New or repeat project	Manpower density
Constructability review	Craft turnover
Relationship with the owner	Experience with owner
Experience with owner	
Local/remote project	
Owner-furnished equipment	
Low Impact	
Delivery system	Close-out and turnover
Contract type	

The second part of this research developed a linear regression equation to predict the magnitude of impact of change orders on labor productivity. The research team found that only six factors out of all the influencing factors have the most significant impact. The linear regression equation to predict the magnitude of impact of change orders on labor productivity (% productivity loss) is as follows:

%Delta = 0.37 + 0.12 Percent Change - 0.08 PM % Time On Project - 0.17 % OwnerInitiatedCO – 0.09 Productivity - 0.05 Overmanning +. 02 Processing Time

Table 1-2 gives the definition of each of the independent factors listed in the above equation. The numbers in column 3 of the table should be considered the limits for the variables in the model. Projects with variables that fall outside these limits lessen the accuracy of the % Delta calculation.

Table 1-2 Equation Factors Defined

Factor	Definition	Limits
Percent Change	Percent of change on project in Terms of original budgeted work- hours	**2.5% to 90%**
PM% Time On Project	Percent of time the Project Manager Spends on the Project.	**0% to 100%**
%OwnerIntiatedCO	Percent of change orders initiated by the owner	**0% to 100%**
Productivity	Did you track productivity for the project? (input[work-hours] output[units installed] The contractor could use one of the following: Track % complete by earned value. Track % complete by actual earned work-hours. Track % complete by actual installed quantities	**0 = NO** **1 = Yes**
Overmanning	Did overmanning occur on the project? [Estimated peak manpower Actual man power] < 0.77	**0 = NO** **1 = Yes**
Processing Time	The period of time between initiation Of the change order and the owner's approval of the change order: 1-7 days = 1 8-14days = 2 15-21 days =3 22-28 days = 4 >28 days = 5	**1 to 5**

This model's limitation is that in order to acquire accurate data, one must operate within the limits of the parameters used to develop the equation, or else inaccurate results will be obtained.

1.2.2 Hanna's Method

Hanna's method quantifies the cumulative impact on labor productivity for mechanical and electrical construction resulting from changes in the project (Hanna et al., 2002). The study developed a multi regression model to predict the loss of productivity as a result of change orders. It also included an indicator variable in the full model called Impact. The variable is used to indicate whether a project was impacted by change orders. This study is a follow-up of previous work conducted by CII research, therefore the results are very similar.

1.2.3 Leonard's Method

Charles Leonard (Leonard, 1988) used 57 projects to draw 90 case samples and develop a model to calculate the effect of change orders on productivity. He represented his model in three graphs: the first for electrical and mechanical projects, the second for civil and architectural projects, and the third for a combination of both types. He considered that all the 57 projects are impacted because they were taken from a consulting firm that specialized in preparing and investigating construction claims. All the samples were taken from extreme cases that went to the claims stage. This fact limits the usability of his model because these extreme cases don't express the typical conditions existing in most projects. Besides, Leonard didn't investigate un-impacted projects to provide a benchmark for comparison between impacted and typical projects

The review of the published methods that quantify the impact of change orders pointed out that these methods can not be used in this research for the following reasons: The CII and the Hanna method used electrical and mechanical projects because of their labor-intensive nature, where the labor cost component of these two industries represents 40 % to 50% of their total costs, which cannot be applied in a typical building project. Another problem is that it is difficult to validate their developed models with high classification and prediction accuracy for new cases because of the low R^2 value (quality of regression model). There are still other factors, which significantly impact productivity, which are correlated in nonlinear fashion. Also, many of these factors are qualitative rather than quantitative in nature. Usually, regression analysis has limited success when dealing with many qualitative or “noisy” input variables (Lee et al., 2002).

The review of the CII study also pointed out that some of the factors that having high impact in the pre-award stage such as “ Bid document rating” and “ Percent change complete” are related to the design documents, which is the main focus of this research.

1.3 Statement of the Problem

Design changes during construction, which are typical in most projects, lead to increased cost, loss of productivity, and delays. These changes are usually originated from approved scope changes or due to design errors and omissions (E&Os) found in the construction documents. These errors and omissions are typically manifested in terms of incorrect or inconsistent dimensions and layouts in the construction documents or by the lack of timely and correct information that is needed to build the project or to meet the code requirements. Among others, E&Os are usually caused by poor coordination and communication among the many parties involved in the design process.

1.4 Objectives and Scope

Change Orders should be avoided or minimized because invariably they interrupt the flow of work, create delays, cause schedules to slip and increase costs, which in turn may generate claims and even costly litigation. Many reasons that might result in these changes have been listed before. The objective of this research is to explore the extent to which change orders resulting from errors and omissions in the design documents are caused by poor coordination and communications, and to determine the extent to which the use of the concept of the 3D parametric building model can be used to minimize or eliminate E&Os, hence minimizes total change orders.

1.4.1 Hypothesis

Design is a very interactive process. It requires inputs from different design specialists with different levels of technical knowledge. Although these professionals work with different input parameters and perceptions to the design process, they should end with a consistent set of drawings and specifications to communicate the design to the builder. To maintain this consistency between the drawings and to ensure design effectiveness, design team members should efficiently communicate with one another during the process. Poor coordination can have adverse impact on the design outputs and may result in many errors and omissions. Consequently, during construction, these design errors will result in associate change orders. This category of change orders is anticipated to have a big share with respect to the total changes that might occur during the project. Meanwhile, these can be prevented or minimized if the produced design drawings would be free from errors and well coordinated. In order to eliminate design errors and omissions, any design change should be documented correctly and properly adjusted in all the existing graphics representations of the design. Using conventional 2D CAD software in handling this problem cannot guarantee the consistency of the solution because of the lack of automated coordination in this software. This type of software creates multiple files to store the design. Consequently, it is not very effective when a change occurs, because the user has to effect this change separately in all of the related files. In most cases this does not happen and significant errors and omissions can take place, leaving some documents unmodified. On the other hand, the concept of the 3D parametric building model has been implemented in commercial software using object-oriented technology. It creates a centralized database storing all the parameters of the design components as well as their interrelationships. Thus, whatever change is made, it is consistently propagated to the entire design object. The author hypothesized that to minimize or avoid change orders due to errors and omissions, one can use the "parametric" or intelligent building model to coordinate changes between design documents, because it generates only one model for the whole building. It comprises intelligent building components, views, and annotations. These are both parametric and are associated bi-directionally through a high-performance change propagation engine, which supports the management of the design changes. Any design change within any certain document can be rippled with all the necessary modifications instantly and completely throughout the whole documentation set because these are different views of one model.

The objective of this study is to validate the effectiveness of the hypothesis and to find out the extent to which the use of this parametric model may help to minimize or avoid these errors and omissions problem, hence reduce to the overall change orders in the project.

1.5 METHODOLOGY

The methodology used in conducting this research consisted of the following tasks:

- Conduct a literature search to define the objective
- Review different research tools to identify one to be used
- Identify a Case study to look in-depth at real-world situations.
- Identify a method for assessing CO impact
- Conduct a survey (Design, Collect Data, Analyze) to verify the hypothesis.

1.5.1 Literature Review

To develop a better understanding of the research objective, a comprehensive literature review has been done. To arrive at a level of confidence of the importance and usefulness of this research, different aspects that are related to the research subject have been considered. First, the various approaches previously presented by other researchers who had dealt with the change orders issue. Secondly, papers that have discussed the management of design information for obtaining better change management system. Then, the previous research efforts that had used computer models to support the process of handling the design changes' conflicts. Finally, the different computer-based techniques that are available in the industry for dealing with the collaboration and management of information.

The review included the following sources:

1. Review of relevant published papers primarily in the ASCE's journals
2. Review of research published by the Construction Industry Institute (CII)
3. Review of computer-based packages that have been developed by different manufacturers
4. Attendance to educational online sessions of a commercial parametric building modeler.

1.5.2 Research tools

The approach that was chosen to develop the work consisted of three main parts:

1. A literature review as mentioned in the above section
2. A case study
3. An online survey

From the start, there was a preference for considering the case study, because it is an ideal tool to look at real-world situations where problems can be directly observed. Besides, it gives a better understanding of why the problem happened as it did, how significant it was, and what considerations should be taken in the future. For clear vision of what could be done to avoid design errors and how it can be done in future projects, the evolution of parts of the design, where E&Os were observed in the real project assuming that Revit was used by all participants was simulated using Revit's software as an example of parametric building modeler. A comparison between the drawings generated with Revit and the original design drawings generated using AutoCAD R.14 was performed to determine whether or not the use of Revit would have prevented or minimized the E&Os observed in the project.

An online survey was also conducted to validate the research hypothesis. The survey provided feedback from industry practitioners in the United States.

1.5.3 Case study

A health care facility that is now under construction in Egypt was chosen as a case study for this research. This type of facility was selected because it represents one of the most complex building types in design and construction, and because data for this project were readily available to the author. The level of coordination required between the phases of the project is tremendous due to numerous building systems involved as well as the vast amount of information that is handled throughout the life cycle of the project. In the case study there were several change orders resulting from design errors and omissions due to lack of proper coordination between both the design drawings of the same discipline and/or one discipline and other design disciplines.

The project's data including drawings, cost, and schedule were carefully studied and analyzed by mapping out the history of the design errors that were discovered during construction. Questions used to investigate the different design changes included: how did they originate in the first place? What was their impact on the cost and schedule of the project? And how they would have been avoided or minimized if the parametric building model had been used during the design phase. The following tasks were conducted:

- Collect the CAD drawings of the project. A copy of these drawings is shown in Appendix D
- Identify the workflow model of the design firm in this project and the way the design information was exchanged to find out the causes of the design's conflicts that had happened during the project.
- Identify design changes due to errors and omissions.
- Map out the reason of their evolution.
- Trace their consequences and identify their impact on both the cost and schedule of the project.
- Simulate some of these problems, which had the most severe impact in terms of added cost and time using Revit to:
    - Observe the capabilities of Revit to manage the information transfer between the different design parties
    - Compare the results with the original procedure previously conducted in the project using AutoCAD .

1.5.4 Change orders assessment

A literature review of the ASCE's published papers, and the publications of the CII was conducted to identify published methods for quantifying the impact of change orders. The main purpose of this literature was to check if these methods could be used to determine the impact of change orders due to E&Os in the construction drawings in the case study.

1.5.5 Survey

A survey questionnaire was conducted as a supporting step to seek factual information and knowledge on change orders that are resulting from poor design coordination, on their percentage to the total change orders, and on how the use of CAD design packages influence both the coordination process and the percentage of the design errors. The questions were first designed, revised, and implemented using HTML format that could be posted electronically on the Worcester Polytechnic Institute (WPI) server. A letter of invitation was written and distributed via email in seeking cooperation and informing the respondents about the research objective. The original intent was to send the survey to the top design firms in the industry in order to correlate the research data with actual experiences. A list of the top hundred design firms was obtained from the ENR magazine website, and the survey distributed to them. In order to increase the % of the response rate, the author decided to post a thread discussion in the Revit's on-line users group, an on-line CAD professionals' group that answers questions, researches products or debates issues. They were invited to respond to the survey. A statistical analysis has been done for the collected data. The result of this analysis can be found in chapter 5

2 DESIGN PROCESS & INFORMATION TECHNOLOGY

2.1 Workflow models

An extensive literature review of the current work flow models has been conducted, to better understand the attributes of a collaborative working environment and to propose a workflow model to be used for documenting, understanding and effectively communicating information associated with a change order. Some researchers referred to the work flow system as: “An application level program which helps to define, execute, co-ordinate and monitor the flow of work within organizations or workgroups. In order to do this, a work flow system must contain a computerized presentation of the structure of the work procedures and activities” (Ellis et al., 1993). Others such as (Hector, 2000) defined it as “the system that is concerned with the automation of processes where documents, information or tasks between participants according to a defined set of rules to achieve, or contribute to, an overall business goal. Whilst workflow may be manually organized, in practice most work flow is normally organized within the context of an information technology to provide computerized support for the procedural automation”.

This review revealed that the way people in the architectural, engineering, and construction (A/E/C) firms interact, collaborate, and communicate throughout the different stages of the construction project’s life cycle can have a profound impact on its success to meet the preplanned expectations. For that reason, workflow management is an essential technique for providing effectiveness and success of any design changes and consequently to the whole project. Neglecting this process will lead the project participants to compromise and not to obtain the required accuracy. Some examples of these work flow models whether they are computer-based or not are:

- Linear Approach
- Circle approach
- Concurrent Engineering.
- Shared Project Model

2.1.1 Linear Approach

In this model (Fig 2-1), the design information is generated in the master bubble (Architect), from which it is transferred to the other design specialties (Structural, Mechanical, etc.) in a linear path. Each designer uses this information and starts to generate his own set of drawings separately until the work is executed. Although there are interdependent design parameters, there is no direct collaboration between the different designers; instead, the information has to be dispatched through the architect. Hence, there are no clear or consistent criteria for transmitting data from one discipline to another. This might cause the dissipation and loss of important information, which eventually result in inconsistent works or undiscovered errors that appear at a later stage.

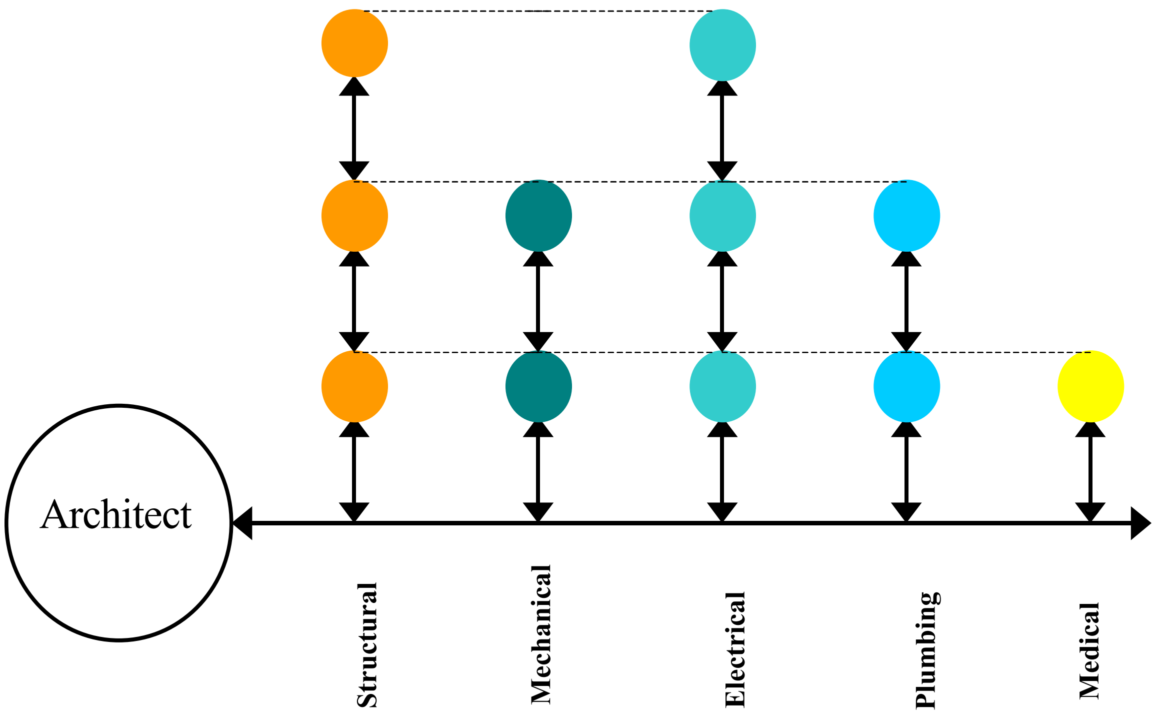


Figure 2-1 Linear approach

2.1.2 Circle Integration Approach

Circle Integration is an approach to technical integration of the design process. It structures the feedback provided by multiple designers in a cycle to ensure that all important considerations are addressed for each design version. This approach (Fischer and Kunz, 1995) proposes an integrated system using a "circle architecture" in which the information passes from one party to the next in a sequential way. They proposed to incorporate the project data by breaking down the project into different applications, each on a separate circle path. At the same time, they linked each application to exactly one predecessor and one successor application. Figure 2-2 shows an example of one application, namely the structural, in which the architect initiates the analysis and propagation to the structural engineer to perform the preliminary design, analysis, and the detailed design. Then, the information passes around the circle to subsequent applications, fabrication, construction planning, scheduling, and cost estimating until it returns to the starting node (Architect), thus completing a feedback loop. The information of any design element can be cycled as many times as needed until the users accept the proposed solution to produce a set of design output. So, changes made at any node of the circle are eventually transferred to the preceding applications without any conflicts or, else if there are any conflicts, they can be properly and timely discovered and fixed.

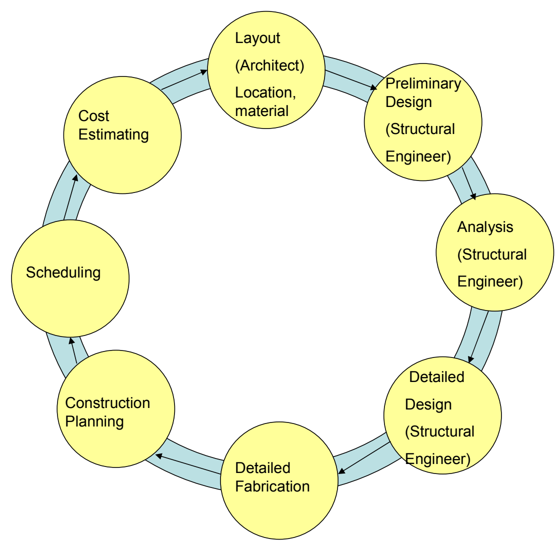


Figure 2-2 Circle Integration

2.1.3 Concurrent Engineering (CE)

The Institute for Defense Analyses defined Concurrent Engineering as a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to involve the developer, from the outset and to consider all elements of the product lifecycle from concept through disposal, including quality control, cost, scheduling and user requirements (http://www.soce.org/).

Integrated Product Development (IPD) is a production philosophy that systematically employs a teaming of functional disciplines to integrate and concurrently apply all necessary processes to produce an effective and efficient product that satisfies the customer's needs. There is no checklist for implementing IPD because there is no one solution, each application will be unique [As defined in the USAFMC Guide on IPD, 1993]. Benefits of CE and IPD include 30% to 70% less development time, 65% to 90% fewer engineering changes, 20% to 90% less time to market, 200% to 600% higher quality, and 20% to 110% higher white collar productivity. [As reported by the National Institute of Standards & Technology, Thomas Group Inc., and Institute for Defense Analyses in Business Week April 30, 1990](http://www.soce.org/).

From the above definitions, it can be concluded that by the development of Concurrent Engineering most of the project processes can be carried out in parallel allowing concurrent input from several users, hence all the project organizations are brought to work together and communicate their expertise at an early stage for the most benefit of the project.

2.1.4 Shared Project Model (SPM)

The SPM is a shared building model in which the entire project related information is stored. Each participant in the project can access the project data at any time and phase of the project. This concept was introduced by the International Alliance for Interoperability (IAI). The main intent of the IAI is to establish a "universal language" at each stage of the project to enable subsequent phase to build on previous information. SPM would retain the critical information throughout the different applications of the project to provide an efficient information management system by eliminating the duplication of the information. With the SPM, the AEC industry would shift from the drawing/layer concept to the object-oriented concept, in which the objects would have different representations depending on the situation and need. Having access to this shared project information set, can alleviate the coordination problems thus increasing the efficiency of the project team and reducing the time required to complete each phase of the construction project (Ken, Herold et al., 2000).

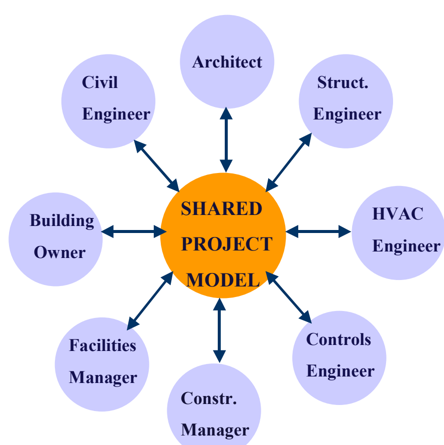


Figure 2-3 Shared Project Model

Hence, it seems that the way the information is being transferred from one party to another has a major impact on the success of any change management. Actually, transmitting the project information in a linear manner and dealing with its components as separate entities often produces errors and omissions problems and doesn't guarantee the required compatibility among all systems. Moreover, these incompatibilities can be accumulated and discovered at later stages during the construction, which result in cost overruns and failure to meet the assigned schedule of the project. However, to avoid this problem of inconsistency, the use of an integrated information system involving all parties of the project working together from the start to coordinate and optimize the required task, is proposed. It is really advantageous for all teams members to be fluent in the same technical language of the others and to realize that the building and all of its systems should be dealt with as an integrated whole, rather than as a collection of isolated ones. That means that in order to apply any modification to the design, we should consider that every single design element or system should not be added, deleted, or modified anytime until it is coordinated and evaluated with the other elements and systems in the whole building package.

All these lead to the conclusion that in order attain a successful change management system that will lead in the end to maximize the effectiveness of the project outcomes, all the project parties have to work together in a well-coordinated environment.

2.2 Information Technology Communications

In the last two decades, the Information Technology (IT) tools, such as Internet communication via electronic mail, coordination via Intranet, and Internet collaboration via project Extranet have had a significant impact on the architectural/engineering/construction (A/E/C) projects. These tools play an important role in gathering and coordinating the fragmented responsibilities of the industry members. From the moment the project starts, both the number of participants and the associated information they generate, grows exponentially with time until it reaches what it may seem as an overwhelming volume. At this level the use of the IT applications become very helpful. IT tools are now widely used to support most of the project activities such as exchanging the information, tracking the project different processes, and facilitating communications among the project personnel regardless of their geographical location.

Not only that, but the use of Information Technology has had a supportive role in handling and managing change orders that originate throughout the project. This has been achieved through:

- The use of Knowledge-Based Systems for effective handling of the change information
- The use of interoperable software packages for efficient exchanging of the change information
- The use of different software such as Expedition™ and Prolog™ for better tracking of the change information

This section provides some examples of the use of IT in different applications dealing with the change orders.

2.2.1 Knowledge-Based Systems

Artificial Intelligence and Expert System computer techniques allow modeling and knowledge based reasoning. Many researchers realized that this type of applications could be used in sharing information and facilitating task integration among the project participants. For example, the Distributed and Integrated Environment for Computer-aided Engineering (DICE), is a blackboard representation that integrates a global database, several knowledge modules, and a control mechanism (Ahmed et al.,1992). Another example is the Stone Rule (from Stone & Webster) which was a proprietary software sold through "Prescient Technology" in which the software is installed on an engineering firm. The design knowledge is customized through a rule base reflecting the specific design practice of the firm.

2.2.2 Interoperability

Interoperability is the ability to exchange electronic information seamlessly and predictably from one software to another (AIA handbook of professional practice, 2002). Hence, ensuring effective data exchange between team members without any loss of information during the transfer process. The idea of Interoperability has been introduced by the International Alliance of Interoperability (http://iaiweb.vtt.fi/). IAI is an alliance of organizations within the construction and facilities management industries dedicated to improve processes within the industry by defining ways of sharing electronic information of the project among the construction industry professionals. Organizations within the alliance include architects, engineers, contractors, building owners, facility managers, manufacturers, software vendors, information providers, government agencies, research laboratories, and universities. IAI dedicates its efforts to develop and promote the use of global standards for the automated exchange of data among computer applications such as CADD, cost estimating, permitting, and scheduling. IAI has defined new standardized object definitions called “the Industry Foundation Classes (IFCs) to retain critical project information throughout the different phases of the project generated by compliant software applications. Having information in this standardized format enabled each subsequent project phase to build on information, previously created or modified. This approach prevents the loss of project information and guaranties its integrity while it is transferred from one party to another as the building is gradually designed and built (Herold et al., 1997)

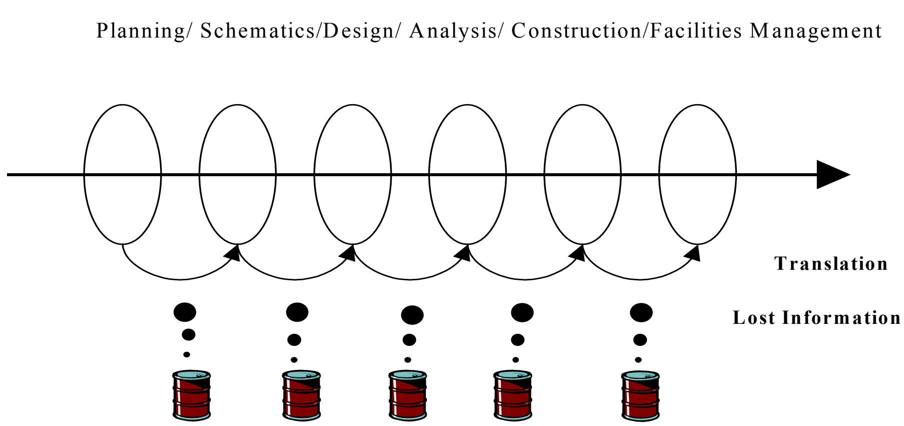


Figure 2-4 Traditional system of exchanging the information

(Herold et al., 1997)

Figure (2-4) shows the traditional system of transferring the information throughout the project life cycle (Planning, Schematic, Design, etc.) where some information may be lost during the transfer, unlike the interoperable system at which the information grows while its transfer from one phase to another (Fig 2-5)

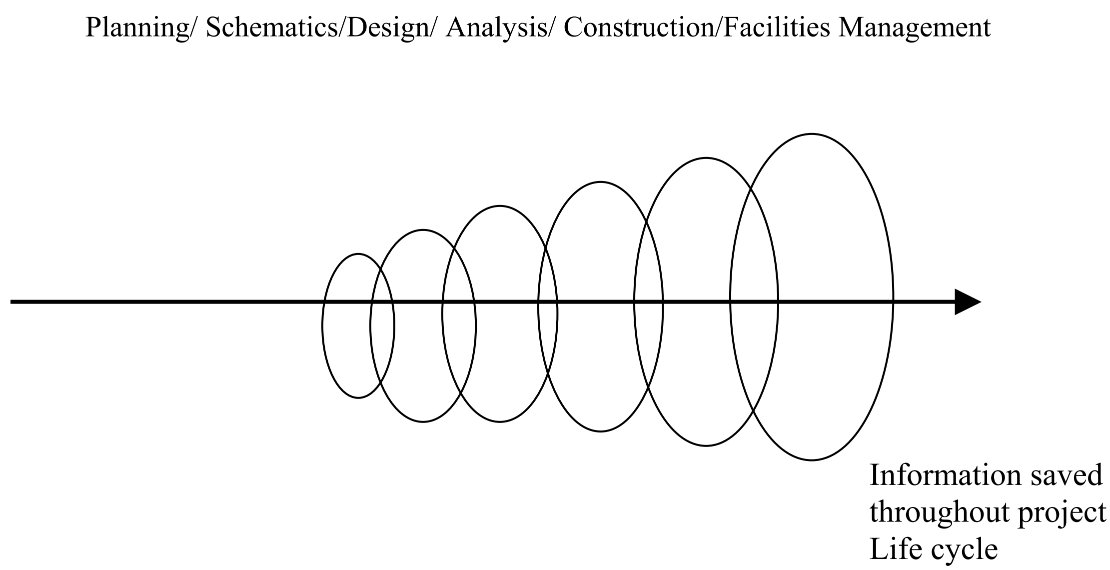


Figure 2-5 Interoperable system of exchanging the information

((Herold et al., 1997)

2.2.3 Use of application software in tracking and analyzing change orders

There are several software packages available in the market used to track and analyze COs. One of these packages is Expedition, which is part of Primavera's Plan-Execute-Control proposed solution used in construction projects. Expedition has several modules that help to ensure an effective management of the project resources.

One of these modules is Expedition Analyzer. It summarizes change orders to facilitate project management decisions. Change orders can be organized by specification section and contractor to quickly identify their sources. (Example project shown in Fig 2-6).

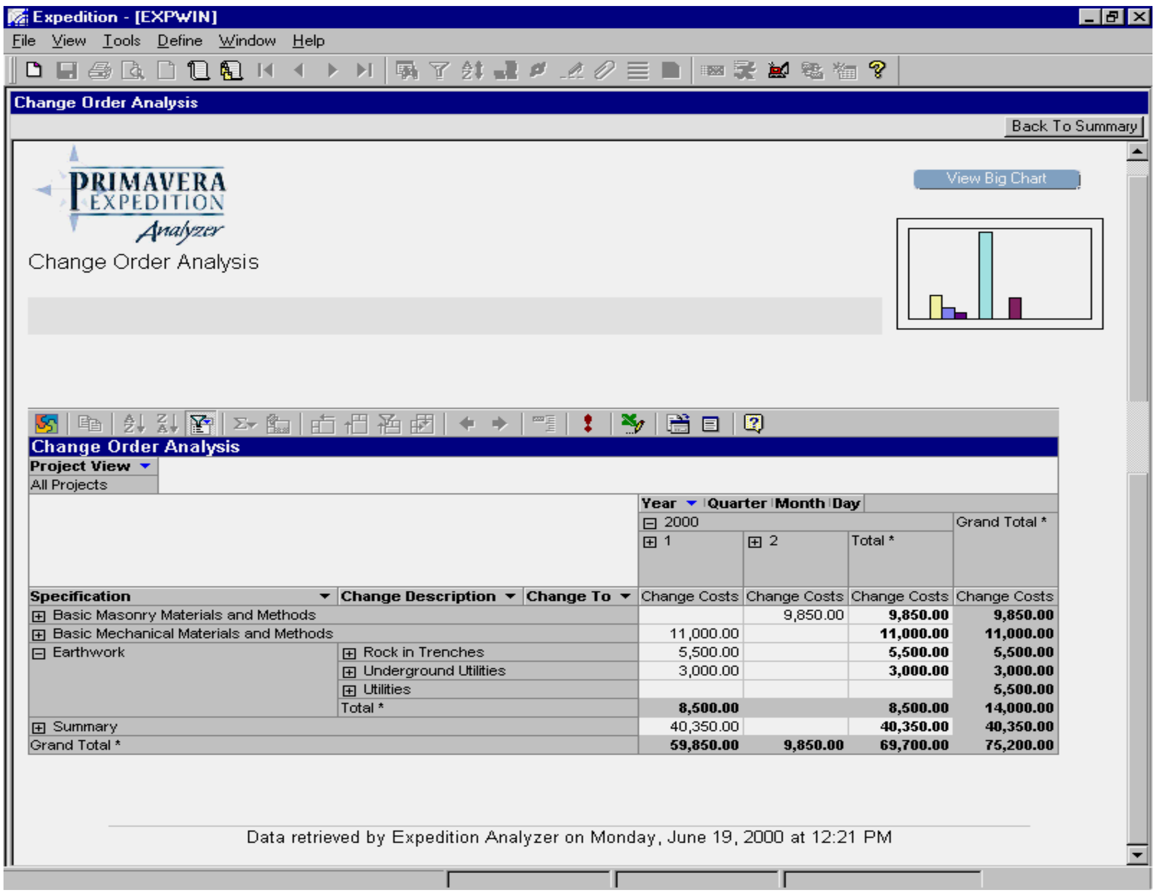


Figure 2-6 Expedition Analyzer in analyzing & summarizing change orders

http://www.primavera.com/products/images/analyzer-change-order.gif

Each change order can be analyzed as follows:

- Analyze program costs by project hierarchy of the specifications sections
- Slice and dice changes by contractor, description, and specification section
- Drill down to single document

- View changes by year, quarter, month, and day

Expedition has another module, which is Expedition Express. It delivers Web-based access to project information stored in Expedition to remote team members and project participants. Expedition Express gives the project managers and executives an instant snapshot of a project status. This presents timely information to allow for faster responses to potential changes, resolve outstanding issues and overdue items. Figure 2-7 shows a snapshot of the current status of an example project

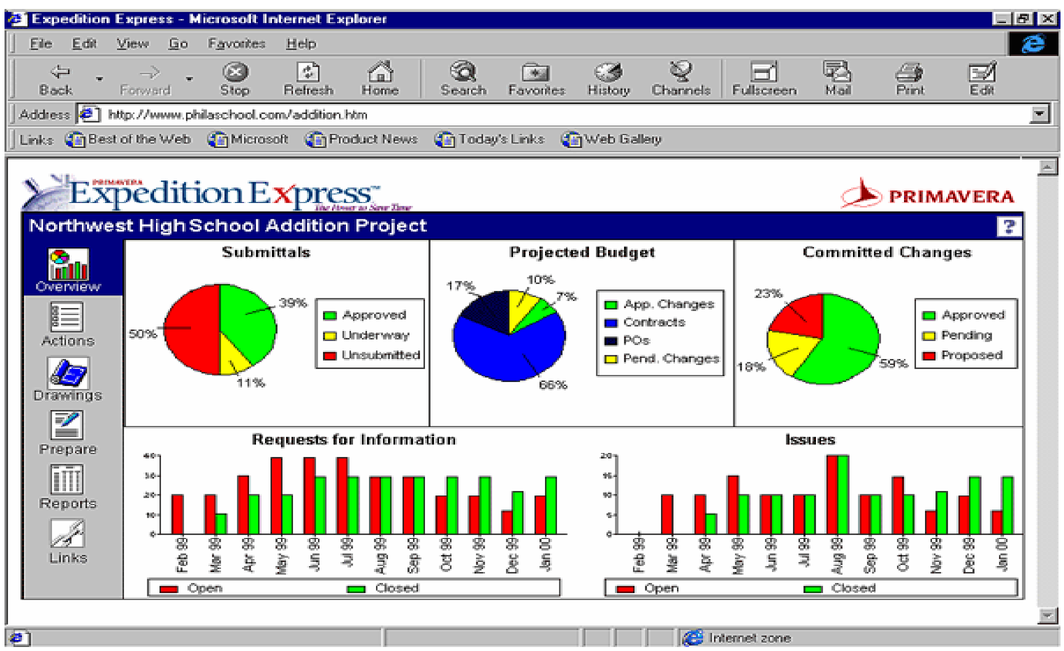


Figure 2-7 Snap shot of the project status in Expedition Express

http://www.primavera.com/products/exp_express.html#analyze

This module can be very useful in controlling design changes by reviewing all related submittals and drawings required to implement a given change. Expedition Express helps to keep the review cycle moving. Architects, designers and consultants can review submittal information and notify the project manager when and if a submittal is approved or rejected. Figure 2-8 shows an example project at which the submittal is rejected.

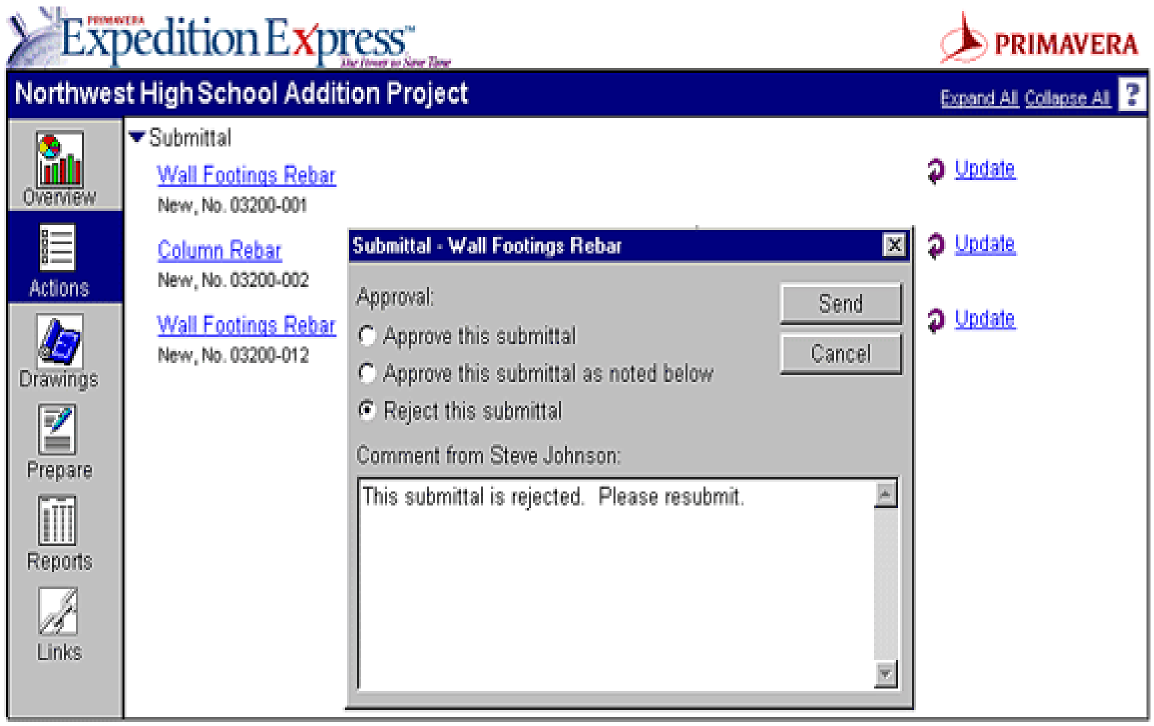


Figure 2-8 Submittals review in Expedition Express

http://www.primavera.com/products/exp_express.html#analyze

Expedition Express keeps everyone on the "same page", since architects, subcontractors, and field engineers can view the latest drawings by displaying CAD files on the screen. Team members can post questions or suggestions and even alert the project manager of any open issues, clarification required and potential problems. This capability leaves all the project teams informed about other team's work, which reduces the possibility of any conflicts that might exist between their trades. Figure 2-9 shows a list of the civil drawings with their revision status and date.

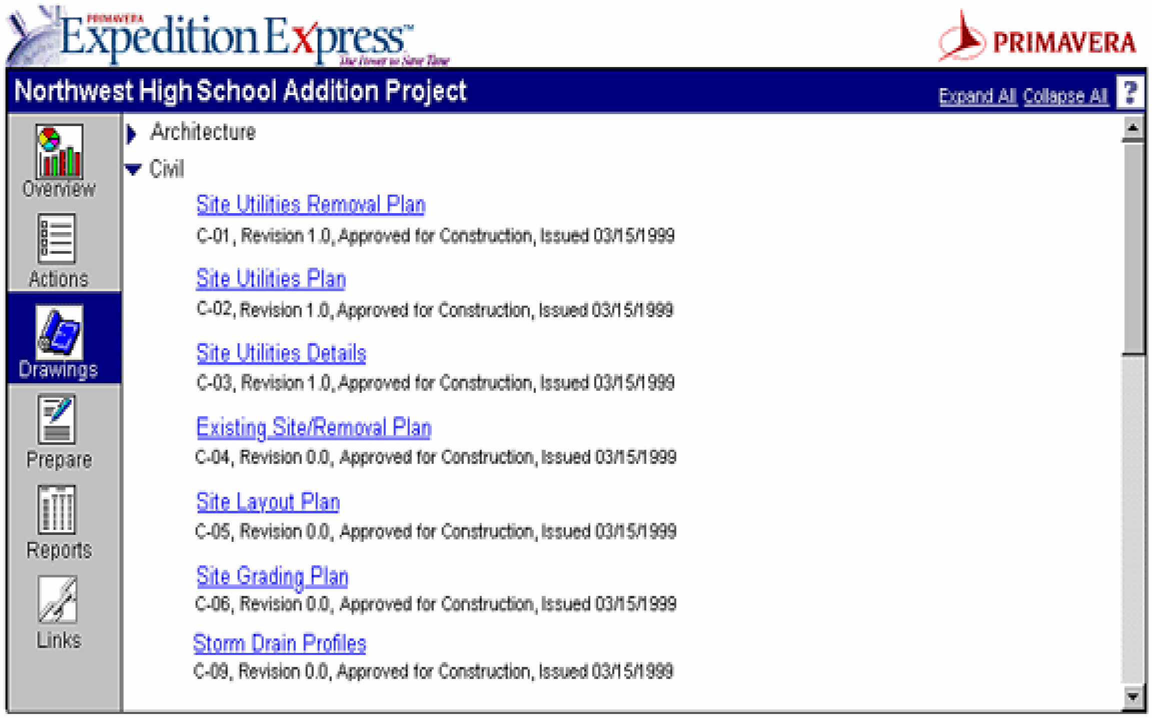


Figure 2-9 Review of the latest revised drawings in Expedition Express

http://www.primavera.com/products/exp_express.html#analyze

Expedition modules help to ensure an effective documentation and management of change orders that happen during the project. Besides, these help to enhance the coordination between different teams' members by accessing all the change related information such as associated submittals and drawings. Yet, these modules do not enable the users to implement a consequence of a given change. That means that Expedition modules help the project members to analyze and summarize a change order, trace, better communicate, and coordinate the associated conflicts and problems, but do not enable the project parties to fix them.

2.2.4 Level of design Automation

The characteristics of advanced computing applications have changed the way engineers produce the design drawings. Design process went through different stages; from hand drafting to semi automated, and then to fully automated.

By hand

For so many years, engineers used to generate design drawings manually by working on the drafting board, and by using essential drawing tools: paper, pencil, T-square, compass, eraser, and scale. To this date, some professionals still do it in this way. However, over the last thirty years this practice has been gradually automated with the advent of CAD and other software applications.

Semi Automated

The introduction of CAD enabled the designers to semi-automate the deign process, and to make quick and relatively accurate drawings with the use of a computer. Unlike the traditional methods of making drawings on a drafting board, with CAD drawings can be created by clicking the buttons of a keyboard, given that the software is already learned. Moreover, drawings created with CAD have a number of advantages over drawings created on a drafting board. CAD drawings are neat, clean and highly presentable. Electronic drawings can be modified quite easily and can be presented in a variety of formats.

Automated

Explicit knowledge and advanced reasoning techniques such as: artificial intelligence (AI) have earned acceptance in the engineering design arena. Therefore, there is a tendency to fully automate design in order to better understand the design intent, to improve its quality, to achieve coherent integration of design solutions, to have multiple representations of the same design elements for better coordination and communication, and to transfer design knowledge for future users.

2.3 CAD Technology

The field of computer graphics has its beginnings back in the early 1960s with the work of Ivan Sutherland who demonstrated a sketching program called *Sketchpad* in 1963. Sketchpad allowed engineers for the first time to generate drawings by using an interactive graphics terminal, and to manipulate them by using a light pen and keyboard. From these beginnings, the field developed rapidly. CAD is very suitable for repetitive and fast documentation. Editing drawings to effect revisions is quick and easy using a CAD product. When working with CAD and a change is requested by the client, the change is done immediately and printed out in a new drawing, or it can be transmitted via e-mail or Internet all over the world almost instantly. CAD enables companies to produce designs documents in less time with a high level of clarity, easy representation of elements, and improved coordination among documents that are almost impossible to produce manually. It also helps to analyze and evaluate alternatives during the conceptual design phase.

2.3.1 CAD Systems

The first CAD systems appeared in the mid-1960s, IBM's DAC-1 for the use by General Motors in car design.

The introduction of personal computers, particularly the IBM PC in 1981 was a turning point for architectural CAD. In 1982, Autodesk introduced AutoCAD, which was the first CAD program for the IBM PC. AutoCAD is a Computer Assisted Design software package for 2D and 3D design and drafting. It is an electronically based medium for creating drawings and images of envisioned designs. For architects, CAD changed the way they worked, drafting tables and pencils were replaced by computer workstations and CAD software. There are many CAD programs available in the CAD industry today. Some of them are intended for general drawing such as: 2D CAD while others focused on specific engineering applications such as: 3D basic modeling for rendering and presentation or 3D intelligent building model.
(http://www.arch.usyd.edu.au/~paul/courses/dc-c/intro_acad/intro.html)

2.3.1.1 Two-Dimensional CAD

In many ways, computer-aided drafting (CAD) is similar to traditional, or manual, drafting. In manual drafting, a draftsman generates graphic objects using tools such as a ruler for straight lines. In CAD systems, the draftsman uses various tools to draw. These tools are usually represented in CAD programs as icons that are grouped together in toolbars that float above the drawing window on the computer display. And, as in manual drafting, these tools indicate what can be drawn, for example straight lines are drawn with a "line" tool. However, this is where the analogies end: in manual drafting, the draftsman draws a line by moving a drawing implement between two points, depositing ink along the way; in CAD, the user indicates the start and end points with the CAD program doing the rest. As well as providing tools to draw straight lines, CAD programs also offer tools to draw circular arcs, ellipses, circles, rectangles, squares, and polygons. Many CAD systems also offer spline curves and polylines. In CAD, each graphic object may be assigned attributes such as color, line type, etc.

In CAD systems, the user draws on a two-dimensional surface of infinite size, which has its origin and two axes (x and y) perpendicular to each other, which are used to determine the location of points relative to the origin. Many CAD systems also provide point specification using polar co-ordinates. In addition to entering points numerically, users can also indicate point locations graphically by directly picking points in the drawing display area. Most CAD systems use a cursor as a visual aid for point selection. A pointing device controls the location of the cursor, which is usually the mouse. Unlike manual drafting, there is no need in CAD to determine in advance the sheet size and scale. There is no drawing scale: all sizes and distances are specified using their full-scale values. It is only at the printing stage that drawing size needs to be determined based on sheet size.

2.3.1.2 Three Dimensional CAD modeling

Many CAD systems permit the rapid generation of models of proposed designs as wire-frames. 3-D basic computer modeling has been used by the design personnel to communicate the appearance of their proposed building design and its material to their clients, planning authorities, engineers, construction managers, and specialist trade contractors. The data in this type of modeling are created and stored as lines, planes, and surfaces, with no other knowledge about the objects presented. The main benefit of using this 3D graphic presentation is to let all the project participants to agree upon the building solution, finishing materials, and form of building elements.

2.3.1.3 3D Intelligent CAD (Parametric Building Model)

In the last two decades Architects, engineers have settled for 2D drafting software that delivered equivalents of paper drawings but did little to aid coordination of drawings within or across disciplines. But in the past few years, the trend toward automatic, electronic coordination of data from all the building disciplines has been growing. In the late 1990s, improved hardware speed and performance supported the development of intelligent 3D design software, or “parametric modeling” (meaning that the CAD software is capable of storing detailed parameters of the building elements rather than simple graphic representation of those elements) or “object-oriented model” (meaning that the building information is created and defined as a collection of objects, not unlike the building itself, rather than a series of lines and planes). Intelligent 3D software accommodates the design work of multiple disciplines in a single presentation to communicate the needed information properly between them. This type of software helps the designers to detect and avoid conflicts between the building components, which eliminate or minimize the costly construction problems that go undetected during design such as pipes that penetrate ducts, ducts that cut through beams, or mechanical equipment rooms that are too small for the machinery they’re intended to house. Benefits go beyond conflicts checking to improved communication and coordination between architects and their consultants throughout the design process and potential results include faster project delivery, lower cost of production, and fewer errors.

A couple of software packages have emerged in the markets which support the use of parametric building model such as: Revit by Revit Corporation which has been acquired recently by Autodesk. (http://www.revit.com/), and ArchiCAD by Graphisoft (www.graphisoft.com)

2.3.1.3.1 Autodesk/Revit

Revit Technology Corporation founded in 1997 launched "Revit software", its first parametric building modeler developed for the AEC industry. Autodesk enterprise acquired Revit in April 2002. Revit's parametric technology offers ease of use in order to enable architects, engineers, owner/operators and construction professionals to transform the entire process by which buildings are designed, constructed and operated over their lifecycle. It makes the use of CAD both easy and natural for architects. Because it is a parametric building modeler, architects work with real-world components like walls, windows, and doors. And the parametric change engine ensures that all drawings and views are always consistent. So, coordination is maintained in the model itself as well as through to the people on the actual projects.

Autodesk/ Revit is a parametric building modeler that comprises intelligent building components, views, and annotations. These are both parametric and are associated bi-directionally through a high-performance change propagation engine. Revit encourages design changes anywhere, anytime by rippling any and all design modifications instantly and completely through the entire documentation set. Autodesk/Revit building components are intelligent building objects behave parametrically. Parameters simply are rules embedded in the object that govern its appearance and behavior. A window might have parameters that allow the architect to define its height, width, number of panels, material and frame style. A wall might contain parameters to define its composition, surface, finish, height, and construction to other walls, columns, floors and ceilings. Parameters can be changed at any time and the complete project will be updated.

For example, a parametric wall understands its relationship to other building components. The wall might have a fixed height, or it might extend up to the next story, or it might be attached to the roof. This design intent is captured in the component. And, if the user wants to change the pitch of the roof above the wall, that change will instantly modify the geometry of the wall without any explicit action required by him. This, in turn, will "revit" (or revise instantly) all plans, elevations, sections, schedules, dimensions and other elements. Revit's bi-directional associativity allows working in a way that the user can drag a wall and changes its dimension, or sketching a rough layout of a wall and then simply typing the dimension values to refine the design. When changing any design element, these changes ripple in all appropriate directions.

2.3.1.3.2 ArchiCAD

ArchiCAD “Intelligent building modeler” was developed in 1982 by Graphisoft ArchiCAD stores all the information about the building in a central database; changes made in one view are updated in all others, including floor plans, sections/elevations, 3D models and bills of material. With ArchiCAD one can access the right representation of the building for each design phase, and for all of the different partners involved in the project. Consultants can receive the building data in electronic format, regardless of which CAD platform they are on, make changes and return the file to you for further work without any loss of the building data in the exchange process. Schedules and bills of materials are available for builders and sub-contractors, as well as drawings of scale-sensitive details. All documents are created while developing the design drawings, remain up-to-date as one proceeds. ArchiCAD's building elements are intelligent building objects. Graphisoft's "Geometric Description Language" GDL is the technology behind these smart building elements. GDL objects contain the information necessary for text specifications, 2D symbols, and 3D models, while taking up very little space on the computer. In addition to material, style, and measurements, the objects can also store manufacturers' data, making product-specific information available to designers, facilities managers, interior designers, and any other professionals who need access to this information.

3 The 3D Parametric Building Model using Revit

3.1 Related Work

Many attempts have been made to improve the integration among all project participants by introducing different approaches. Some researchers have focused on representing design information and recording design rationale. Example of that approach is the "Design Recommendation and Intent Model (DRIM) as an ontology for design rationale and SHARED-Design Recommendation and Intent Management System (SHARED-DRIMS)" as a system for conflict mitigation based on this ontology, (Pena-Mora, et al. 1995). This research was based on the view that: (1) The designers' perspectives are expressed in their design rationale; (2) a system for capturing the design rationale needs to represent and manage design intent evolution, artifact evolution, and relationships between intents and between intent and artifact; (3) a design rationale system needs to capture its information in a non-intrusive manner by providing part of the design rationale; and (4) a system for conflict mitigation needs to provide active computer support for the negotiation between multiple participants

Other researchers such as Platt (1996) focused on design management of civil engineering projects through process-centered approach than data centric modeling. He discussed that the data-centric model main function is to store, retrieve and manipulate the data, but it cannot capture the inherent logic of the process. By contrast the process-centered model, which focuses on the transformations that occur with time that helps to identify the conditions that create the dynamic behavior. He used the learning cycles of soft systems methodology (SSM) and grounded theory to guide the process. Platt also combined the three approaches of walk-through scripts, role developments, and role activity diagrams (RADs) to have better understanding of the process.

Furthermore, there is some research efforts related to managing design changes, for example Wang et al. (2001) developed a knowledge-based multi-view constraint solver in order to manage design changes for the multi-view models. The proposed knowledge-based approach extends the method for single-view problems by combining the concepts of entity projection lines and entity projection rules to deal with multi-view constraint schema. The presented inference example and the design example demonstrate the viability of the proposed method.

Therefore, such work can complement the general effort put forth on using a 3D parametric system to manage the design changes for multi-view models. However, as only lines, circles, and arcs are discussed in this work, more entity types and constraint relations are needed to be included to address the more complex multi-view problems. Besides, the authors admitted that further testing is still required to improve the stability of the multi-view constraint solver.

Most of the researchers dealt mainly with a single design team, rather than multiple design teams. They were largely focused on activities such as tracking design files, restricting access to such files, maintaining past versions of files, notifying users of file changes, and performing electronic sign offs. While these features are beneficial, they are not sufficient alone to manage the complex process of design, particularly when design intent and rationale also change due to the lack of proper communication and the inability to visualize and evaluate the consequence of the change. There is a clear need, therefore, for an effective approach to address this crucial problem (Hegazy et al, 2001). Finally, the author came to the conclusion that this coordination issue could be tackled by the automation of design information exchange process through the use of the parametric building model in the production of design drawings.

For the purpose of this study, Autodesk /Revit software will be explored in detail as an example of a software package that supports the parametric building model. Autodesk /Revit is available at WPI and provides the students with technical support, on-line training, and access to other resources. In the next section, the main concepts and principles of Autodesk /Revit will be introduced.

3.2 Concepts & Principles of Autodesk/Revit

In Revit, the building levels are defined as planes. Objects are associated to these levels, so that changes to a level's height automatically propagate changes to the linked objects. (see Figure 3-1).

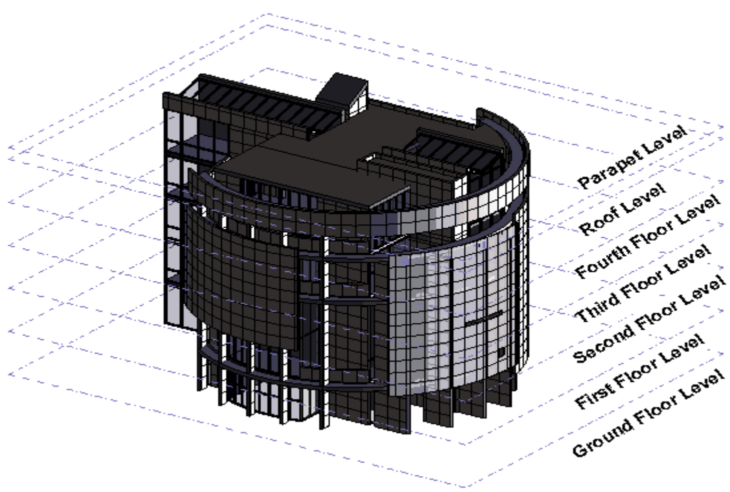


Figure 3-1 Building levels as planes in Revit

(http://www.revit.com)

Revit provides the user with the basic building components enabling the creation of a functional Single Building Model. These components are called families and there are several different types. There are System Families, Standard Families, and Families in place.

- A System Family, which is pre-defined within the program, modifiable by the user using preset parameters, such as levels, walls and floors. The user can modify and define new types by modifying its parameters.
- A Standard Family can be created by defining the geometry and parameter in the family editor. Objects such as doors and windows are examples of these. Many different types can be made for this family and used throughout the project.
- A Family in Place is created within the project. It is dependant upon the model geometry. These can only be used in the project they were built in; therefore they are used for objects that are unique to the project. For example, custom guttering, a unique reception area desk, ornate elevation treatments etc.

Revit objects can be displayed at coarse, medium or fine levels of detail (see Fig.3-2). As with traditional CAD, objects can simply be toggled on or off for visibility purposes, or as with Revit family objects be toggled on or off depending upon their viewing direction.

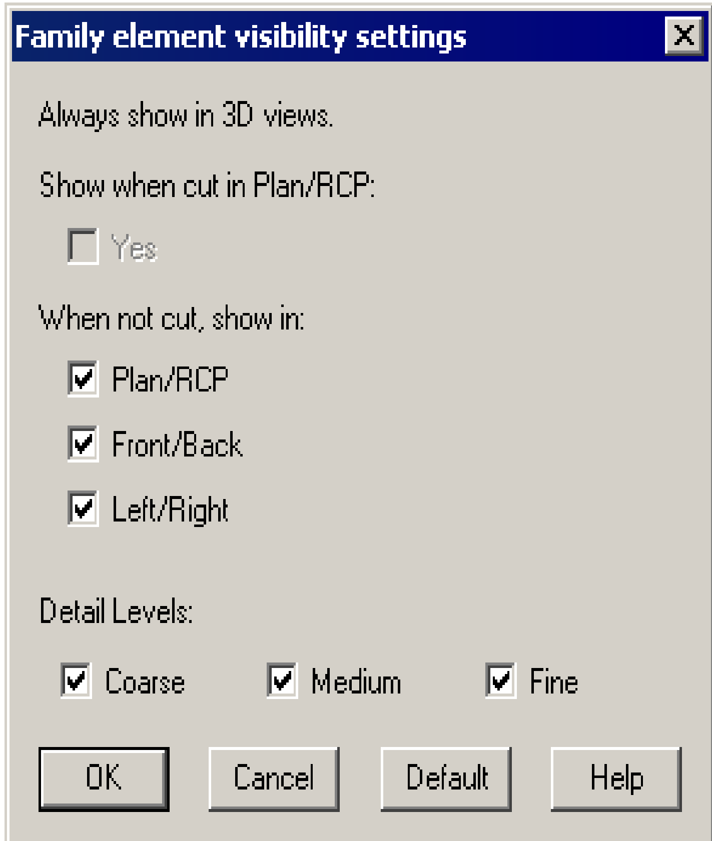


Figure 3-2 Family element visibility dialogue box

In Revit, objects are not layered as in traditional CAD packages, but are controlled using sub-categories. A subcategory is a property of a family that defines its display by setting up the line weight, color, and pattern. For example, for a window a subcategory can be assigned to the wood trim and a different subcategory to the glass (Fig 3-3).

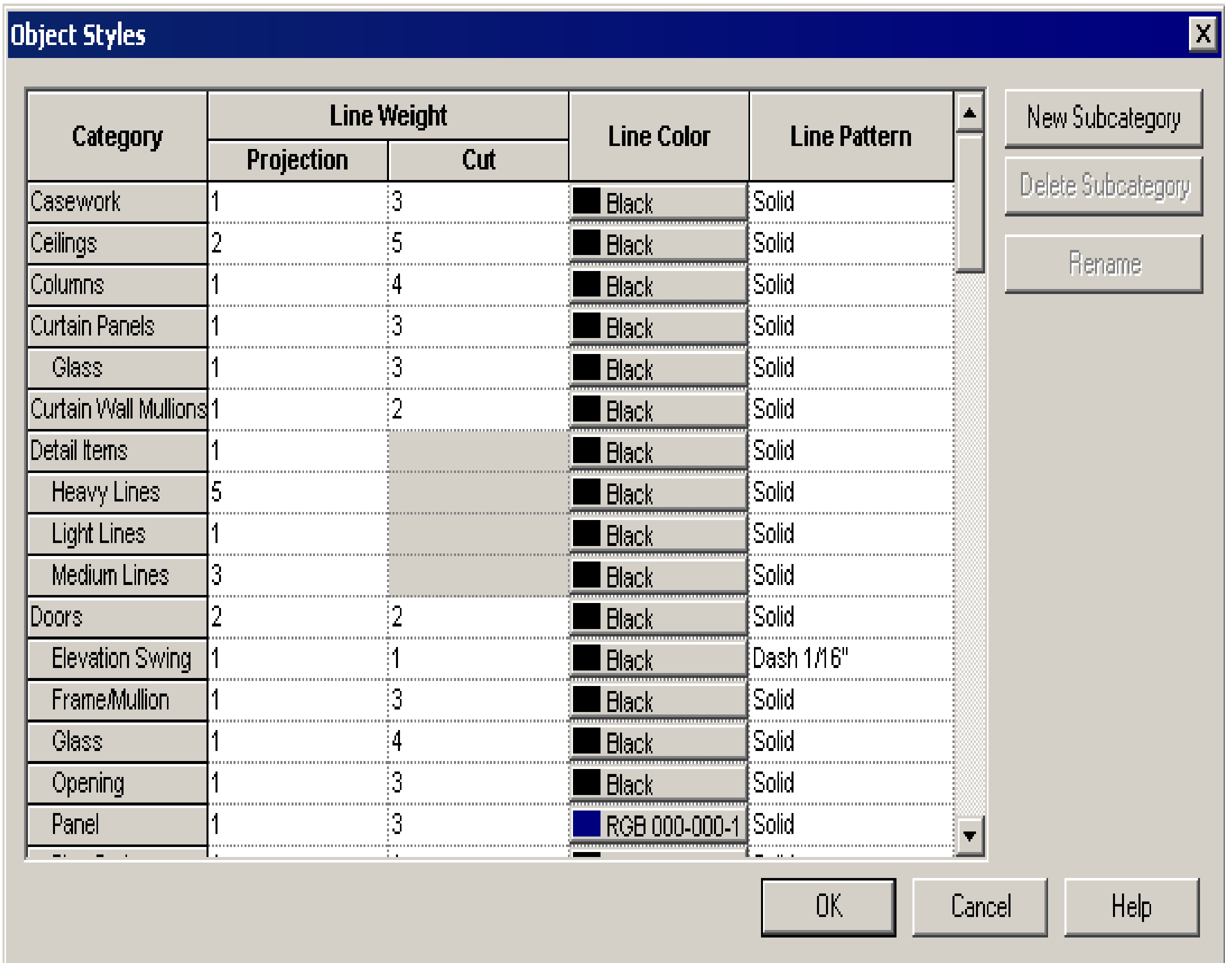


Figure 3-3 Object Style dialogue box

Within Revit, objects can be defined as mutually dependant (e.g. doors and windows are dependant on walls), or stand-alone (e.g.: furniture).

Revit is able to read and import data from a wide variety of different CAD packages. Such data can be used to provide underlays of existing conditions, site information or to link to standard details. As well as importing external data, Revit can export to a variety of industry standard CAD file formats (DWG, DGN, DXF)

The Revit Project Browser displays the model files in a logical tree structure. The browser provides views of the Single Building Model, in plan, sections, elevations, and 3D views. (see Fig 3-4). All these views are multiple representation of the same model.

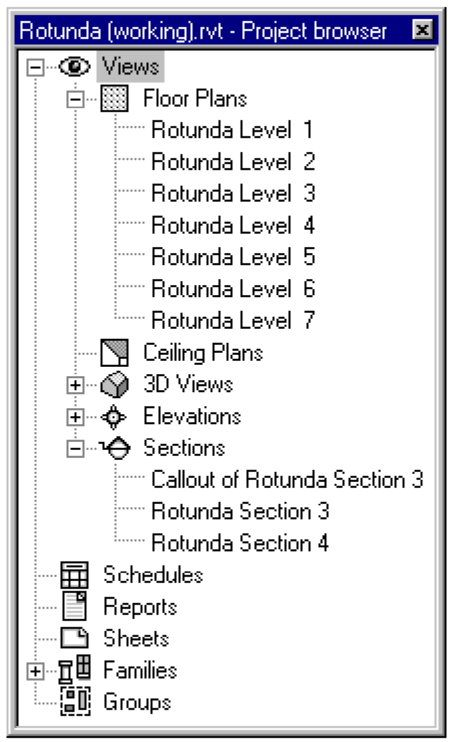


Figure 3-4 Project logical tree structure dialogue box

Revit drawing view scales and levels of detail are specified individually for each view of the model enabling, for example, a general arrangement drawing of the ground floor plan at a coarse level of detail at 1:500 scale, whilst a copy of that view could display at 1:50 scale with a fine level of detail. Within the coarse level of detail (at 1:500), walls would be displayed with a user specified fill style (e.g. solid fill), while the fine level of detail (at 1:50) would enable display of the external cavity walls with all components detailed and appropriately filled / hatched (Fig 3-5).

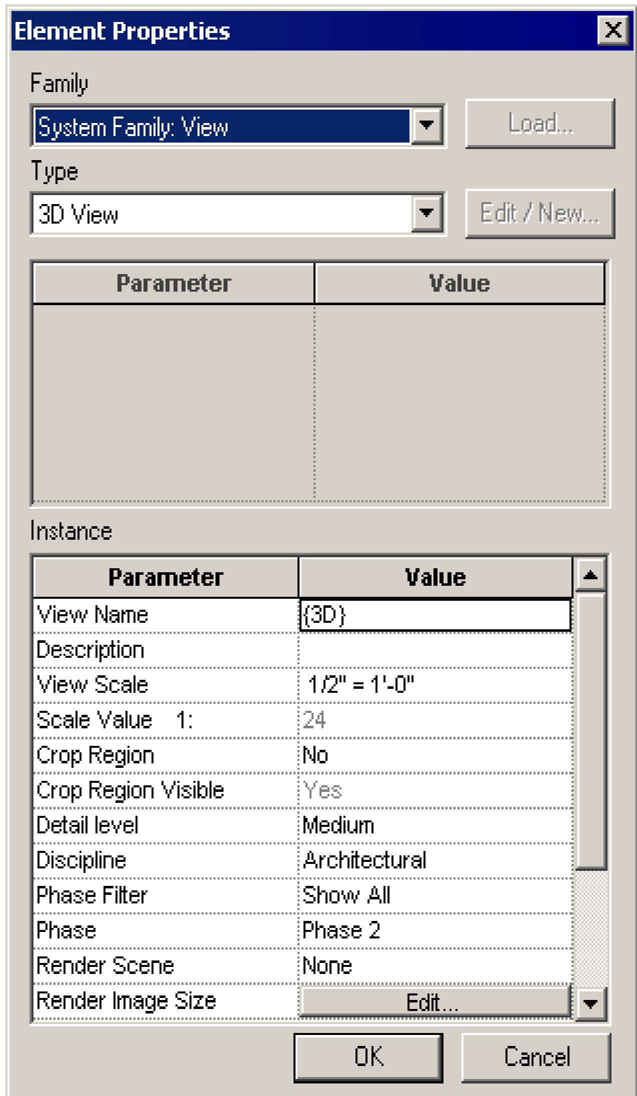


Figure 3-5 Elements properties dialogue box

Using Revit, one can create drawing sheets containing title-blocks, upon which assembling all various views and call-outs (enlarged details). Schedules are specified as views and can either be displayed on drawing sheets or export as text files to external programs. Three-dimensional shaded, perspective and clipped model views may also be assembled. Once complete, sheets can be output to plotting using standard printer/plotter drivers (Fig.3-6).

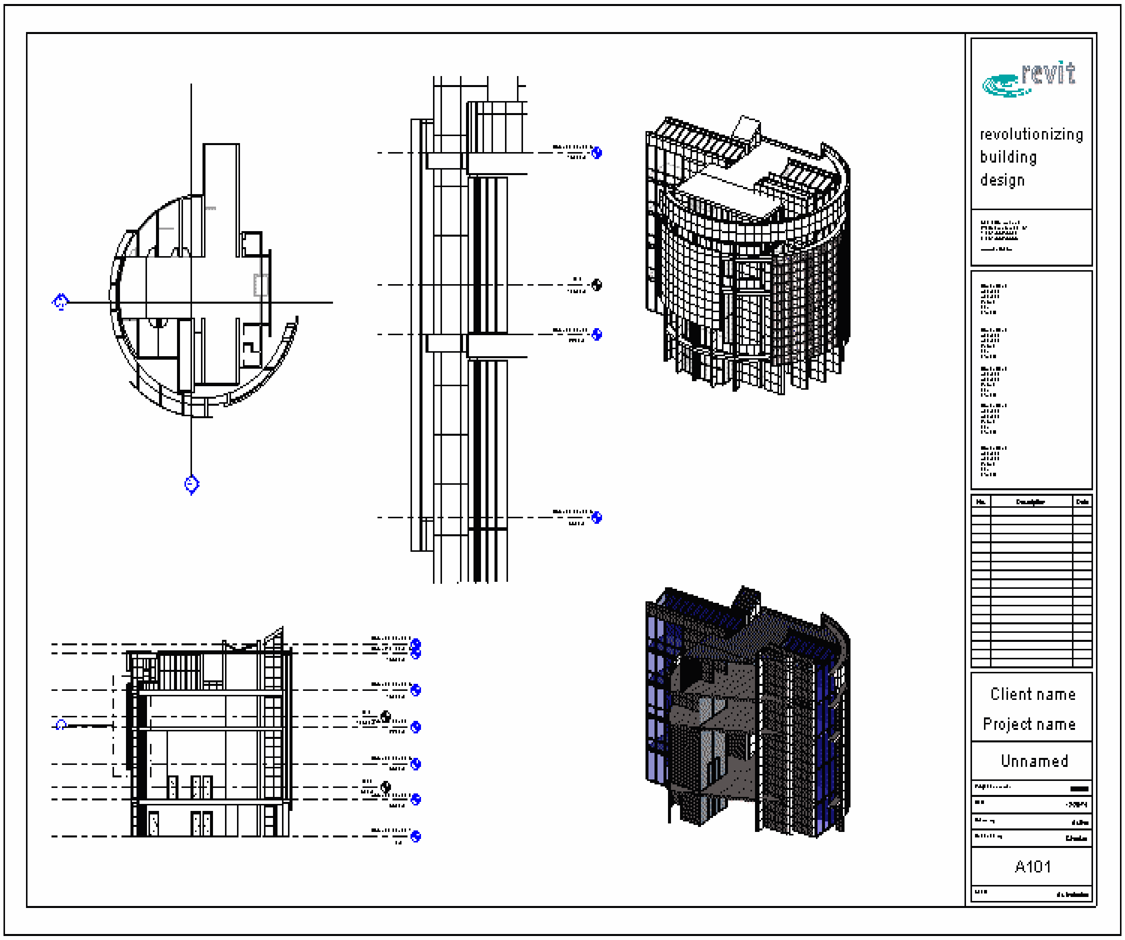


Figure 3-6 Example of a Revit's printed drawing sheet

Source: www.revit.com

3.3 The role of Revit in managing the project information

Revit offers the opportunity to work within an integrated model-based approach, providing a holistic, project-based view of a building's design and definition. This creates a building model that facilitates access to building information, enabling tighter integration of the different design phases.

The role of Revit in coordinating the design documents is similar to the project manager role in the construction projects as follows:

- It enables the project staff to maintain the required consistency between their different disciplines throughout the project life.
- It helps the project members to figure out the possible conflicts between the different users.

This coordination role of Revit is primarily dependable on both the worksets and the concurrent building assets (CBA) features.

3.3.1 Revit Worksets

A workset is a collection of building elements (such as walls, doors, floors, stairs, etc) in the building. Only one designer may edit each workset at any given time. All other team members will be locked out from this workset preventing possible conflicts in the project.

Revit's worksets can be used to propagate and coordinate changes between designers. With using this feature team members can add elements to their worksets and see the latest changes done by other team members to make sure that the project design is progressing in a well-coordinated manner. Besides, they can save their work to a local file on the network or their own hard drive and publish work to the other team members whenever they choose.

3.3.2 Concurrent Building Assets (CBA)

The different users of Revit are working in a reciprocal manner at which all the parties are mutually dependant on the built-in database that controls the relationship between the different components of the building. This is achieved through the Concurrent Building Assets (CBA) concept introduced in Revit 4.0. The CBA captures the information about the development of the project for other building drawings and documentation. As a result, additional information about the project is simultaneously created enabling architects and construction professionals to quantify the scope of a project's content and materials. CBAs capture and maximize the value of information by making it available in the format that is most familiar and appropriate to the various professional disciplines in architecture, engineering and construction. Concurrent Building Assets are always coordinated with all other CBAs in the project by Revit 4.0's parametric change engine.

An architect, for example, viewing a framing plan or bracing elevation from a structural engineer can choose to see it as an architectural floor plan or building section. The steel framing will be shown as the architect wants to see it instead of as a framing drawing. Any individual Concurrent Building Asset, in this case information about the structural properties of a building, is presented as required and is reliable because of its guaranteed consistency. That is because all different views originate from the same model, not as separate files.

Another CBA is the quantification of a building project's business data into relational database tables that are created automatically by the act of drafting the building's plans and construction documents in Revit. Since the quantity information CBA is in the form typically used by construction professionals for estimation, they no longer need to measure drawings to create those estimates or to export geometry from CAD drawings that is then used by some applications that can calculate volumes of concrete from the geometry information provided. The architect who creates this CBA simply documents the building graphically using Revit as he or she normally would. The single entry of graphical data into the parametric model for the usual purpose of designing and documenting a building results in the automatic creation and multiple use of Concurrent Building Assets for each discipline in the project.

One example of the power of this quantification is the measurement of the amount of concrete required to construct a building. Revit provides the amount of concrete in the building directly as data in these open tables. This data is immediately useful to building professionals with minimal additional effort.

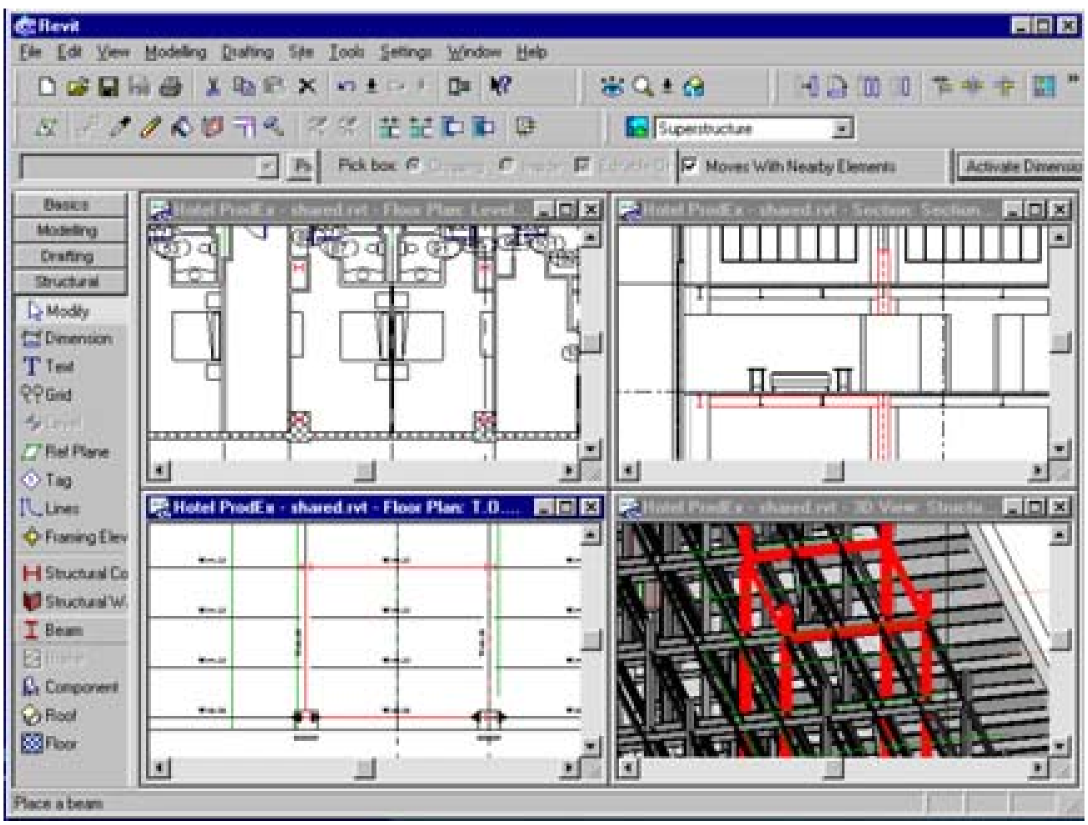


Figure 3-7 Project drawings in progress

Source (http://cadalyst.com/features/1201aecinterop/revit.htm)

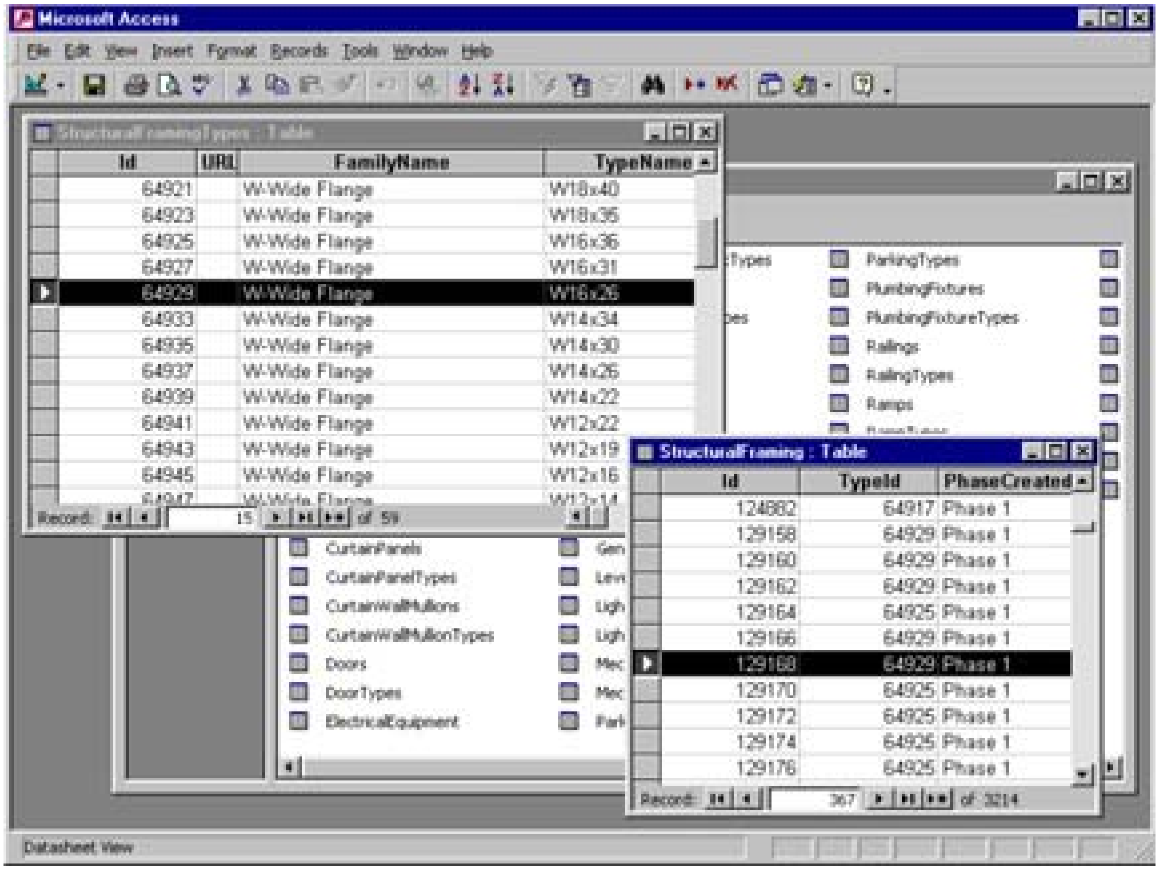


Figure 3-8 Project data imported in Microsoft Access

Source (http://cadalyst.com/features/1201aecinterop/revit.htm)

Revit exports building model data in ODBC format for use with any compatible database.The top image shows a drawing in progress (see Fig. 3-7). A change to any view causes a change to the underlying building database and is reflected in all other views. The bottom image shows the same data, but exported to an ODBC-compliant database, in this case Microsoft Access (see Fig. 3-8).

4 CASE STUDY (Dar-Essalam General Hospital)

Figure 4-1 DGH Main Façade

4.1 General Description

Dar-Essalam General Hospital (DGH) is $ 45 million dollars, eight floors facility. It is located in the southeastern part of Cairo facing the Nile River in a relative highly populated area. This hospital is considered to be one of the primary general hospitals owned and operated by the Egyptian Ministry of Health and Population. When construction is completed in the mid of 2003, this will be one of the ministry's purpose-built regional hospitals designed to bring comprehensive, affordable and appropriate healthcare to the community. This 400-bed hospital will support a comprehensive array of acute and ambulatory clinical services in a vibrant and dynamic environment. Mutually reliant upon its many partners within the Cairo Region, DGH will provide patient care in an environment embracing innovation and recognizing tradition.

DGH will have 6 main surgical suites (including one dedicated trauma room), one Burn, 2 Cardiac, and 2 Obstetric (Labor and Delivery). It will also encompass cardiac, prenatal, trauma, neurosciences, renal disease and nephrology, and respiratory diseases departments.

Approximately 1,200 healthcare employees' staff will be working in that Hospital. In addition it will play a vital role in the in-service education of nurses, therapists, technicians and other health professionals.

The project was procured using the Design-Bid-Build delivery system. The following organizations are involved:

Owner: The Egyptian Ministry of Health and Population (MoHP).

Architect: Integrated Consultations Company (IC).

Contractor: The Arab Contractors Company (AC).

Figure 4-2 shows the organization chart for the project.

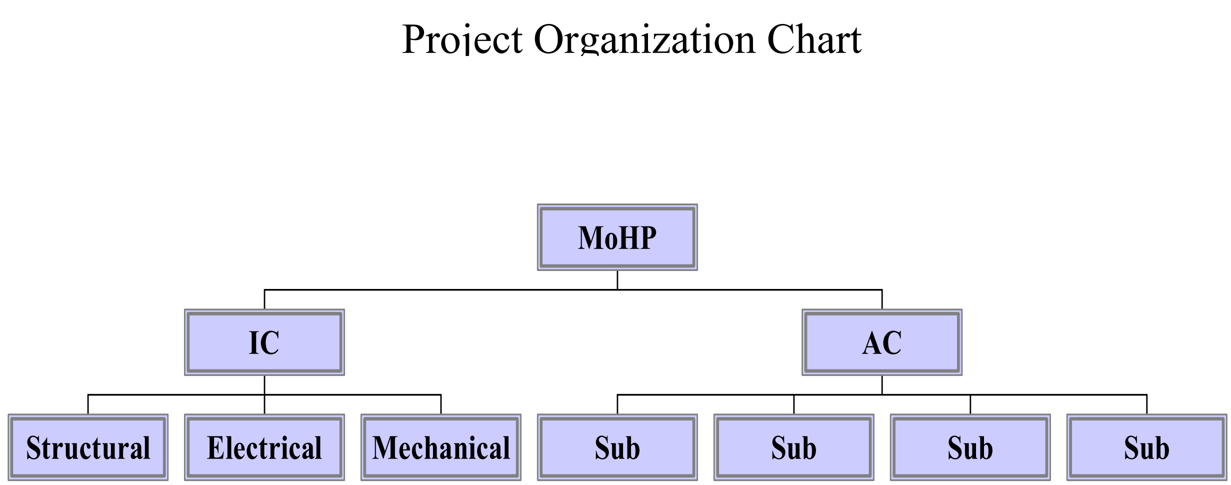


Figure 4-2 DGH Project Organization Chart

The design of this facility started in early January 2000 and the construction started in the mid of the year 2000 and the expected date of completion is mid 2003.

During the construction of this health care facility there were a number of change orders that increased both the initial cost of the project by $2,786,000 (6%) and the schedule by 6 months. Among those, some change orders worth of $834,000 (2%) and 90 days time delay were due to design errors and omissions. The reason behind those E&Os, which were discovered during construction, was due to poor coordination between the different design team members.

4.2 Workflow model analysis

The design process was divided into three phases: preliminary, design development, and final design. In each phase, the information exchange proceeds in a cycle as shown in Fig. 4-3, which starts by the distribution of the architectural drawings by the architect (IC) to the different specialty sub-consultants. Each sub-consultant reviews the documents, generates his own conceptual design, and responds respectively with a list of modifications to fit in his/her design requirements. These responses were done through e-mail messages or office meetings. Usually it is at this point where conflicts or misinterpretations occur. The person who sends/ receives the mail or attends the meeting was not necessarily the one who actually produced the design. Consequently, he/she might misinterpret the information while transmitting it to other design personnel. Possible design errors were created at each transfer step and accumulated by sending this "defective" drawing to another design specialty to build on it. Moreover, another potential for the occurrence of errors lies in the possibility of exchanging outdated drawings among the different design teams.

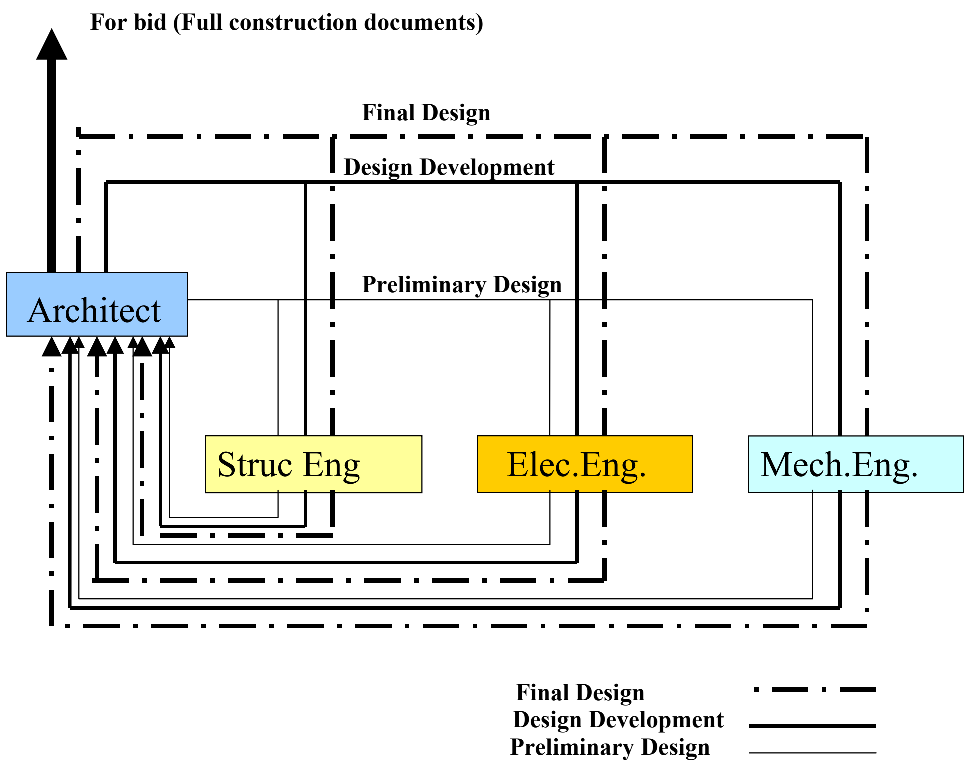


Figure 4-3 Workflow model of the design process

4.3 Design errors and omissions analysis

The change orders due to errors and omissions that were discovered during construction in this project were thoroughly analyzed and categorized as follows:

1. **Design Changes due to the inconsistencies between the mechanical system and other disciplines:**

Change Order 1-1

This change was initiated due to conflict between the structural engineer and the mechanical engineer. The structural engineer designed the slabs of the entrance hall and the entrance shed as one unit without considering the separation between the interior environment and the exterior. At the same time he did not consider the false ceiling that hides the A/C ducts. This omission was generated because the structural designer forgot to place the beam specified by the architect, and since the structural consultant's representative, who attends the regular meetings, is not the original designer, this omission was never discovered until the time of construction. Another reason that accumulated to this problem was that the reviewing process of all the relevant participants, architectural, structural, and mechanical, was performed improperly, despite the fact that A/C ducts were comprehensively mentioned in the specifications. In order to fix this problem, a steel beam had been placed to achieve the required separation and to hide these ducts. (Fig 4-4, Fig. 4-5)

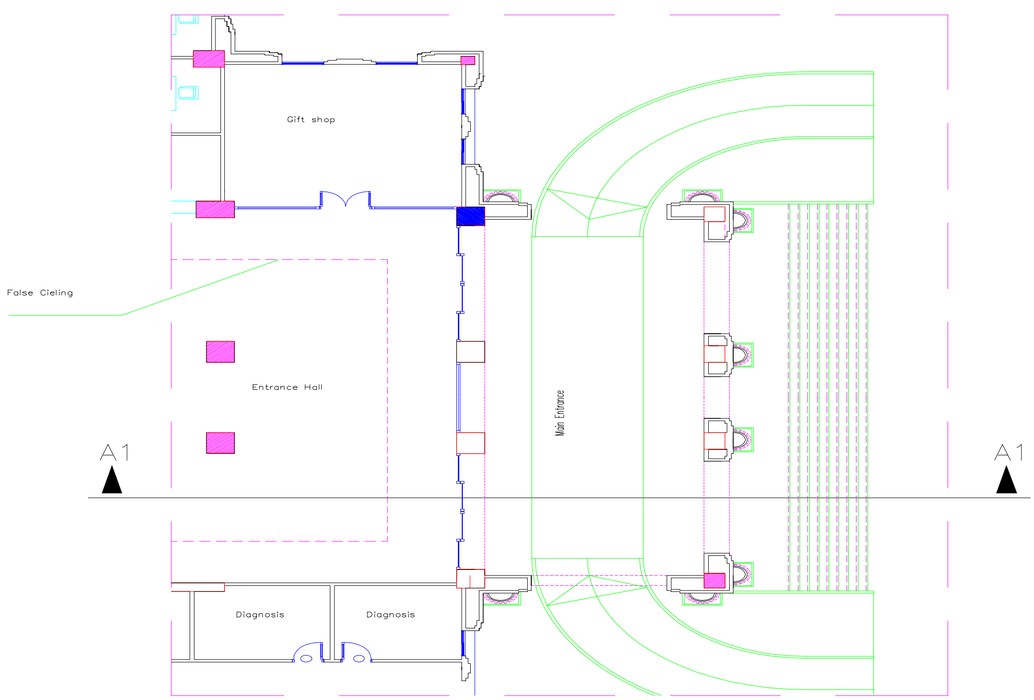


Figure 4-4 Plan view of the main entrance

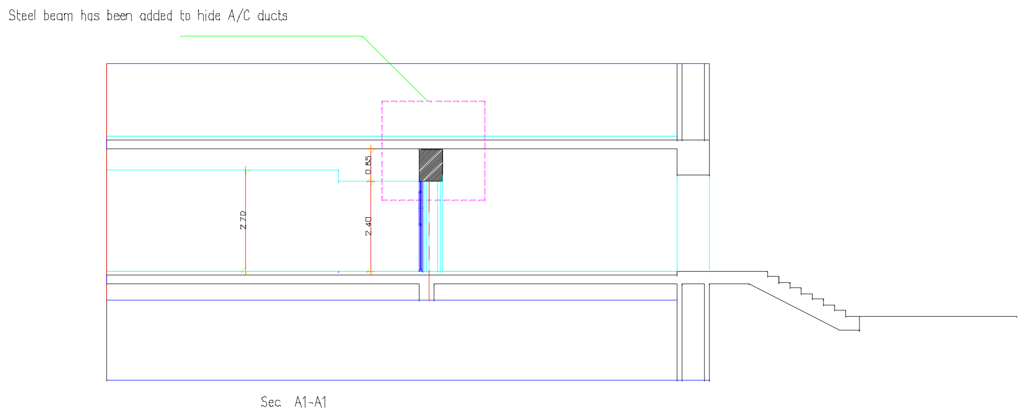


Figure 4-5 Sec A1-A1 shows the added steel beam location

Impact

As a consequence of this design error the cost of the project was increased by $14,230 (0.03% of the initial cost) as well as the schedule, which incurred a net delay of 10 days. Table 4-1 shows the breakdown of this change order.

Table 4-1 Impact of change order 1-1 on both cost and schedule

Item	Cost	Duration
Installation of an extra (18 m) steel beam	$11,400	2 days
Exterior Finishes	$980	4 days
Interior Finishes	$1,100	5 days
Painting	$750	4 days

Change Order 1-2

This change order was caused by uncoordinated work between the architect and the mechanical engineer. The mechanical engineer designed the A/C system with air handling units (AH) to be placed inside the false ceiling of the restrooms. This decision reduced the clear height of these rooms from 2.55m to 2.15m (Fig. 4-6). This height is not complying with the architectural requirements. In order to overcome this problem the A/C design had to be changed allowing the clear height to be at least 2.55m. Thus, these AH Units were relocated to other rooms distributed across each floor. The function of these rooms was changed from visitors' lounges to mechanical rooms in the architectural drawings. This lead to the loss of the visitor's lounge space, which were substituted by placing seating chairs along some parts of the corridors.

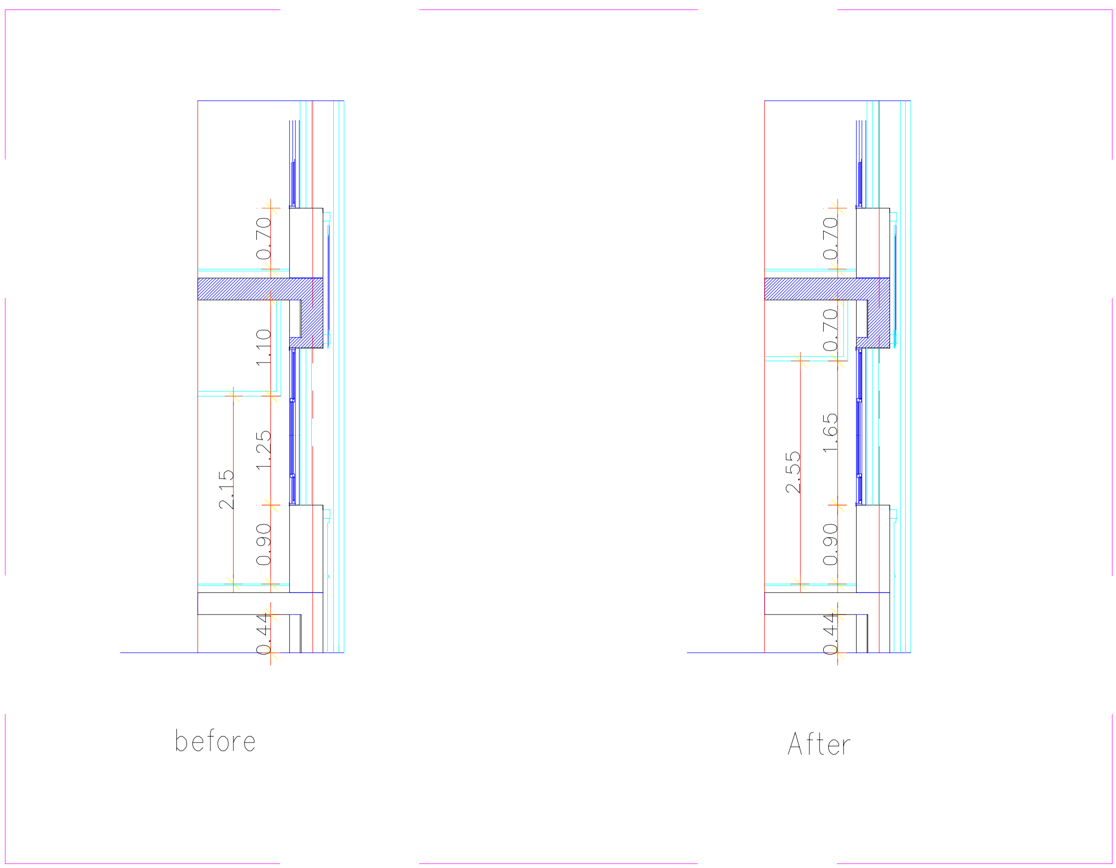


Figure 4-6 Section view related to change order 1-2

Impact

As a consequence of this design error the cost of the project was increased by $318,865 (0.7% of the initial cost) as well as the schedule, which incurred a net delay of 65 days. Table 4-2 shows the breakdown of this change order.

Table 4-2 Impact of change order 1-2 on both cost and schedule

Item	Cost	Duration
Duct works	$26,450	33 days
Air Handling units	$162,655	0 days
Interior Finishes	$106,000	58 days
Masonry	$6,160	16 days
Doors	$17,600	9 days

2. **Design Changes due to the incompatibility between medical equipment installation and other disciplines**

Change order 2-1

This change was caused by the conflict between the windows sill height and the labs' furnishings. The labs' cabinets required the sill height not to be less than 0.9 m. This height was shown at 0.4 m in the original drawing. In order to solve this problem, the sill height was increased to meet the furniture requirements, which in turn led to some modifications in the façade design. Figure 4-7 shows the plan view and the section view of the lab. A considerable part of this problem was eliminated, because the architect adjusted the size of the windows before bidding the project. However, he forgot to change the height of the sill in the drawings as well as the quantities of the masonry and the finishes required.

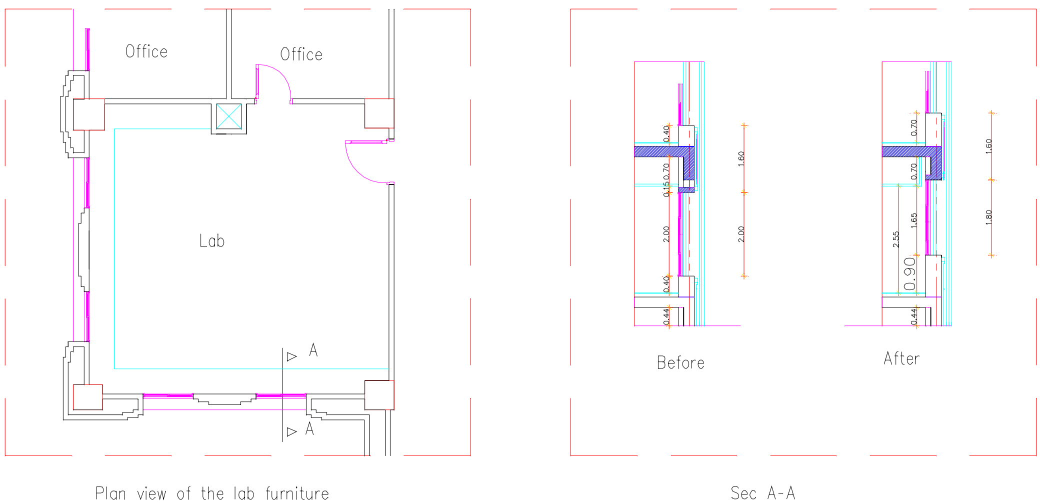


Figure 4-7 Plan view & Section related to change order 2-1

Impact

As a consequence of this design error the cost of the project was increased by $58,167 (0.1% of the initial cost) as well as the schedule, which incurred a net delay of 29 days. Table 4-3 shows the breakdown of this change order.

Table 4-3 Impact of change order 2-1 on both cost and schedule

Item	Cost	Duration
Masonry	$ 11,733	12 days
Interior Finishes	$ 18,666	20 days
Exterior finishes	$ 27,768	25 days

Change order 2-2

Another change was issued due to the impossibility of the installation of renal dialysis equipment within the specified location of some windows. This equipment should be mounted to a wall; therefore an interior wall was placed to fulfill these requirements, while keeping the exterior façade untouched in order to maintain the architect's aesthetic taste (Fig 4-8). This conflict was discovered during construction.

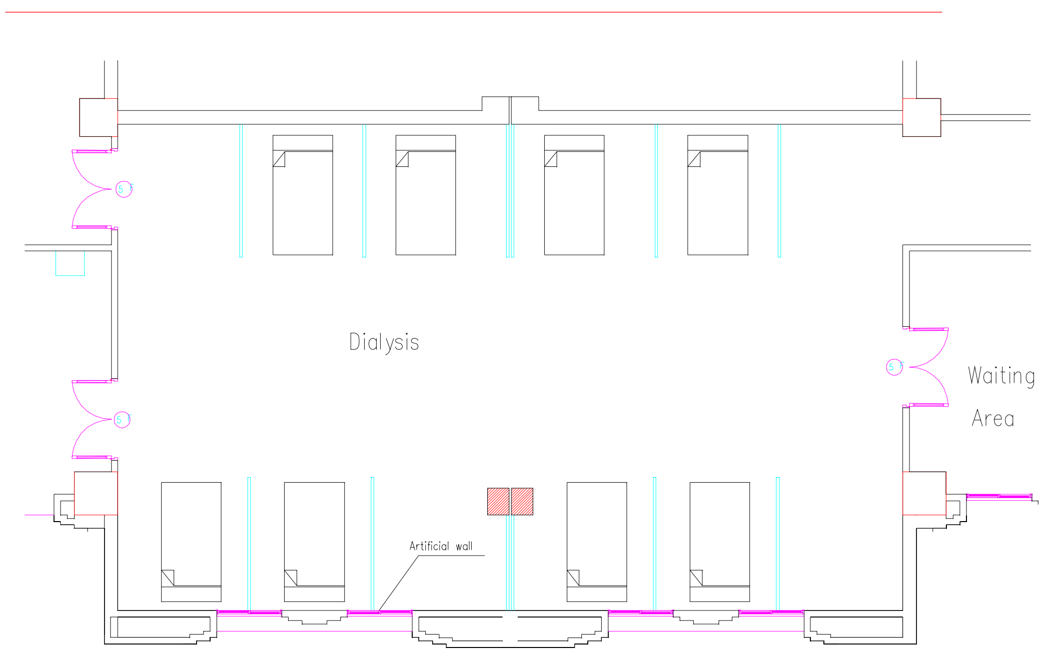


Figure 4-8 Plan view related to change order 2-2

Impact

As a consequence of this design error the cost of the project was increased by $4,920 (0.008% of the initial cost) as well as the schedule, which incurred a net delay of 6 days. Table 4-4 shows the breakdown of this change order.

Table 4-4 Impact of change order 2-2 on both cost and schedule

Item	Cost	Duration
Drywall	$ 1,680	1 days
Interior Finishes	$ 840	3 days
Electrical work	$ 2,400	3 days

Change order 2-3

There was a conflict between the windows sill's height in the architectural drawings and the Intensive Care Unit (ICU) Furniture. The Biomedical engineer didn't want an opening, so an artificial wall has been built to enable furniture setting of the room generating this change order. This inconsistency discovered during construction. A plan view of the Intensive Care Unit and a section -view before and after adding the wall are shown in (as Figure 4-9 and Figure 4-10).

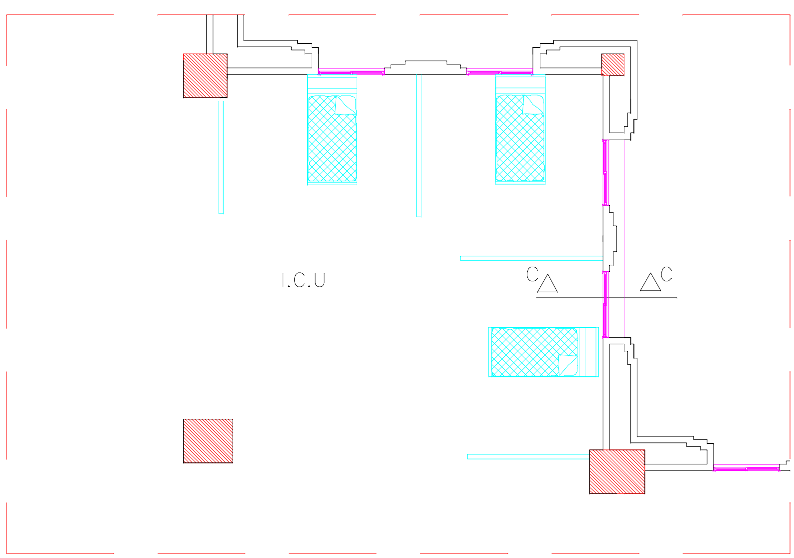


Figure 4-9 Plan view related to change order 2-3

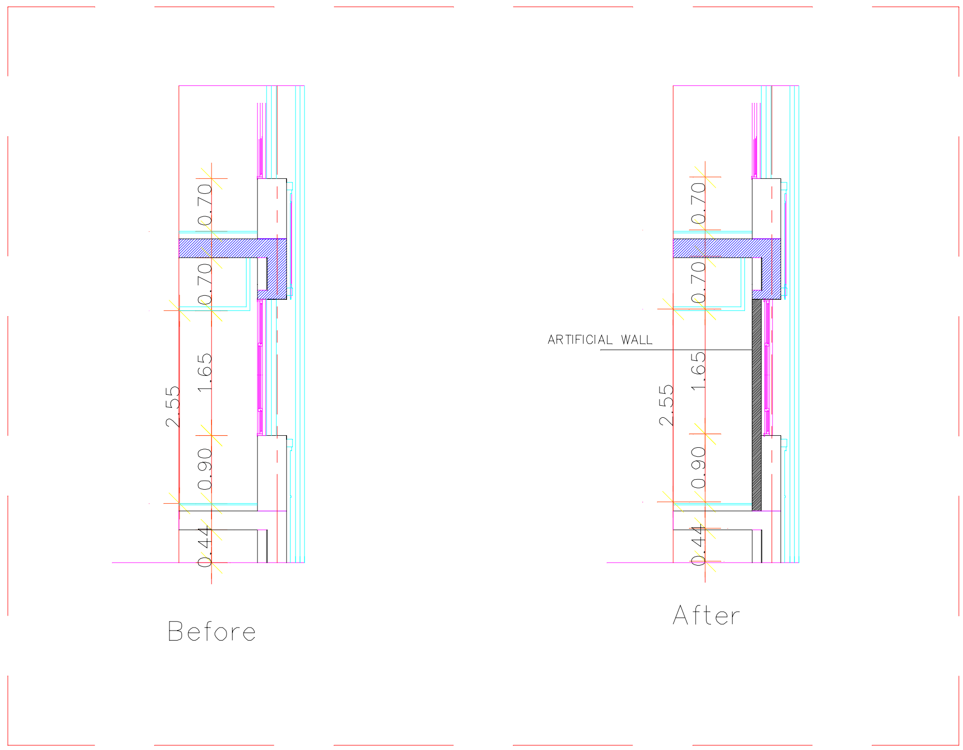


Figure 4-10 Section related to change order 2-3

Impact

As a consequence of this design error the cost of the project was increased by $9,840 (0.02% of the initial cost) as well as the schedule, which incurred a net delay of 8 days. Table 4-5 shows the breakdown of this change order.

Table 4-5 Impact of change order 2-3 on both cost and schedule

Item	Cost	Duration
Drywall	$ 3,360	2 days
Interior Finishes	$ 1,680	5 days
Electrical work	$ 4,800	5 days

3. **<u>Design Changes due to the incompatibility between architectural drawings and schedules</u>**

<u>Change order 3-1</u>

This change arose due to the incompatibility between some of the doors' sizes in the architectural drawings and those in the schedules. The doors were mistakenly drawn in different size than those stated in the schedule. This mainly resulted from the architect's mistake of drafting the restroom's door with a smaller width (0.92 m) than the standard code required width (1.19m). Later, he discovered this error and edited the door's width in the drawings but he forgot to transfer this modification to the doors' schedule. The estimator prepared his bill of quantity from the doors' schedule and the job was bid for the smaller size. This error was repeated in all the restrooms all over the hospital (260 restrooms). It was discovered later during the construction. A change order was issued to justify this incompatibility error (Fig. 4-11).

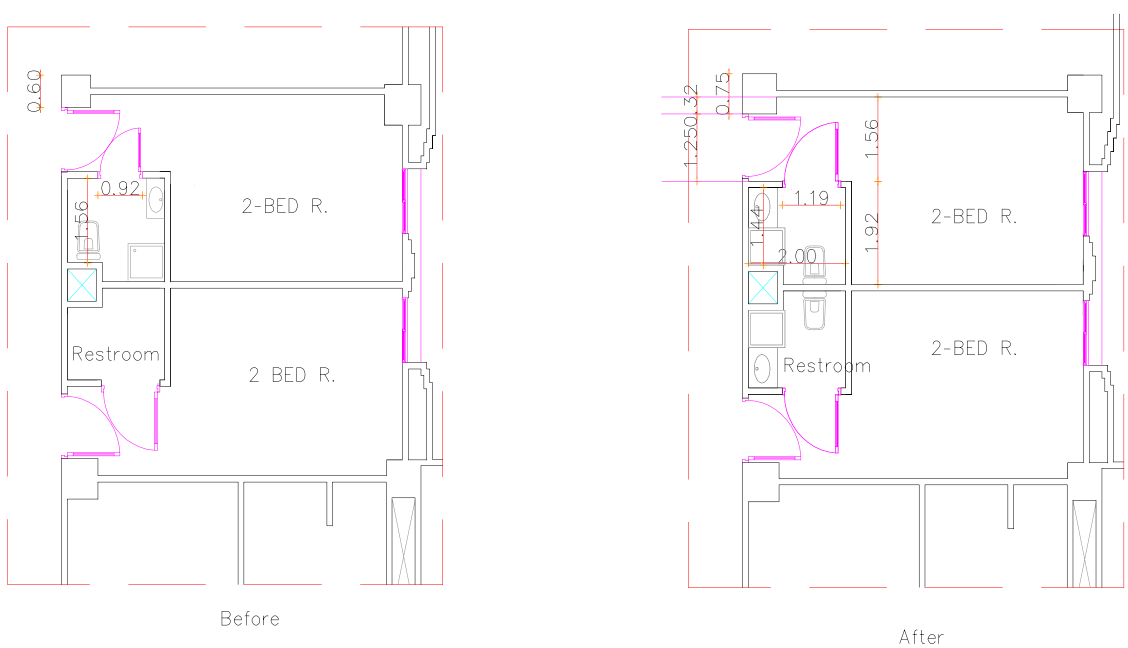


Figure 4-11 Restrooms' plans related to change order 3-1

Impact

As a consequence of this design error the cost of the project was increased by $437,304 (1% of the initial cost) as well as the schedule, which incurred a net delay of 49 days. Table 4-6 shows the breakdown of this change order.

Table 4-6 Impact of change order 3-1 on both cost and schedule

Item	Cost	Duration
Masonry	$ 6,336	3 days
Interior Finishes (ceramic tiles)	$ 10,368	5 days
Doors	$209,600	21days
Plumbing works	$211,000	45 days

The impact of the above mentioned change orders due to errors and omissions on both the cost and schedule of the project are shown in Table 4-7. These E&Os increased the initial cost by $843,326 and incurred a net delay of 167 days. Not all of these 167 days were on the critical path of the project. Approximately 90 days of them were on the critical path, while 77 days were maintained within the float of the project

Table 4-7 Summary of the change orders due to errors and omissions

CO#	Δ Cost	% Δ Cost	Δ Time
CO# 1-1	$14,230	0.03%	10 days
CO# 1-2	$318,865	0.70%	65 days
CO# 2-1	$ 58,167	0.1%	29 days
CO# 2-2	$ 4,920	0.01%	6 days
CO# 2-3	$ 9,840	0.02%	8 days
CO# 3-1	$ 437,304	1%	49 days
Total	$ 8433,326	1.86%	167 days

After analyzing the different E&Os, it is concluded that the changes mainly resulted from poor coordination either between the design drawings within the same discipline such as the incompatibility between the doors' sizes in the plan view and their sizes in the schedules, or between one design discipline, namely architectural, and other disciplines such as mechanical, structural, and electrical. For instance, conflict between the required clear height of the rooms by the architect and the mechanical engineer and the conflict between the architectural drawings and the medical equipments were common design errors.

By investigating the Autodesk/ Revit, it was found that it's parametric engine and the worksets feature can help the different teams of the design to technically communicate and coordinate their work. The first set of errors that occurred due to inconsistencies within the same discipline drawings could be taken care of automatically with the help of the parametric engine. It helps to maintain the consistency of each design element all the way through the different documents, since they are just several views of the same model. The other set of the errors could be tackled by coordinating the inter-relationships of the same design elements between the different design personnel. This can be achieved by sharing the design information and keeping it updated by enabling the "worksets" feature of the software. In the next section , the author is going to show how this could be done by using Autodesk/Revit.

<u>Simulation of same-disciplinary conflict</u>

Change order 3-1 was chosen because it yielded the most provoking impact in terms of additional costs to be simulated using Revit. The typical plan view of the patient's room was drafted using Revit (Fig. 4-12). Once the plan view was drawn, the schedule of the doors is automatically generated by pressing insert schedules and can be formatted in any desired format to describe these doors (Mark, Assembly Code, Description, Height, Width, etc.) (Fig.4-13). The door size was changed to simulate the real situation of that change (Fig. 4-14), hence the doors schedule was automatically updated, unlike the case in the original drawings generated using AutoCAD, in which the architect has changed the door's size in the drawings to meet the code requirements, but forgot to transfer this change to the door schedules (Fig. 4-15)

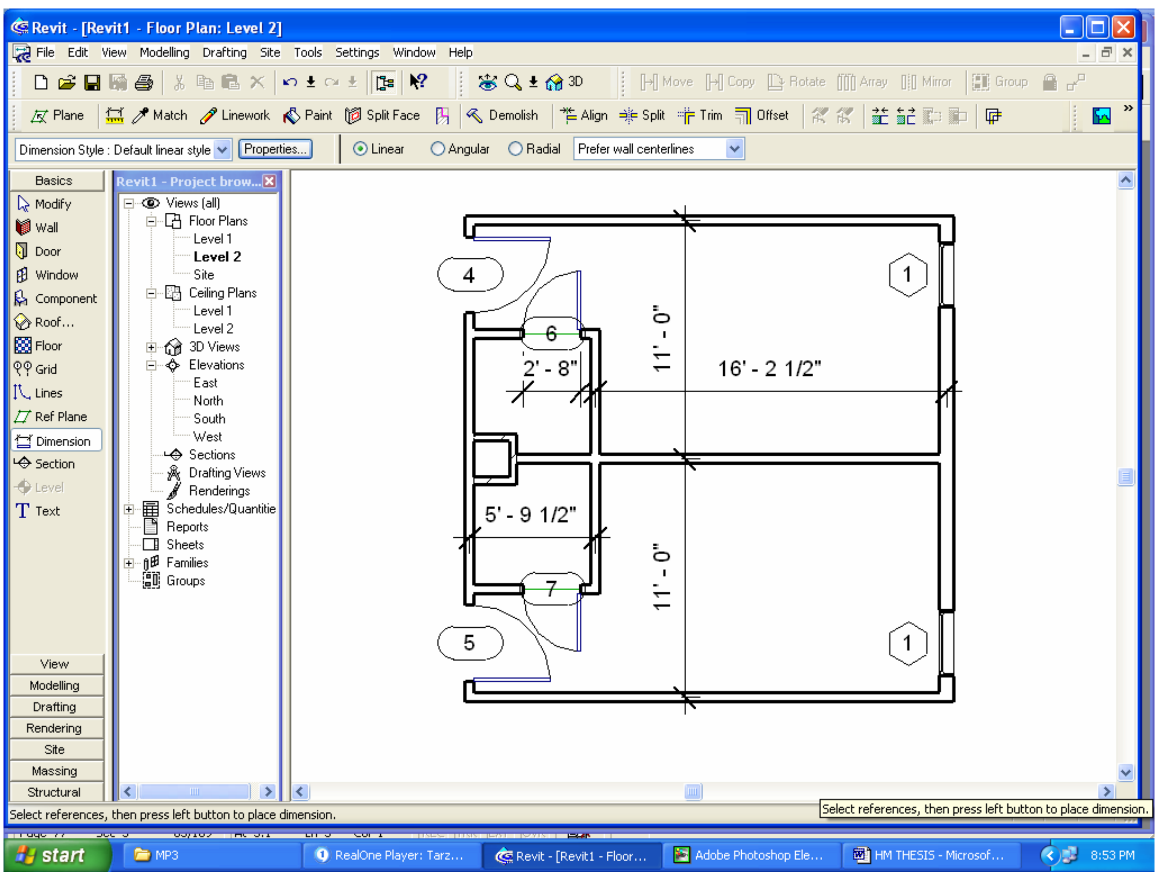
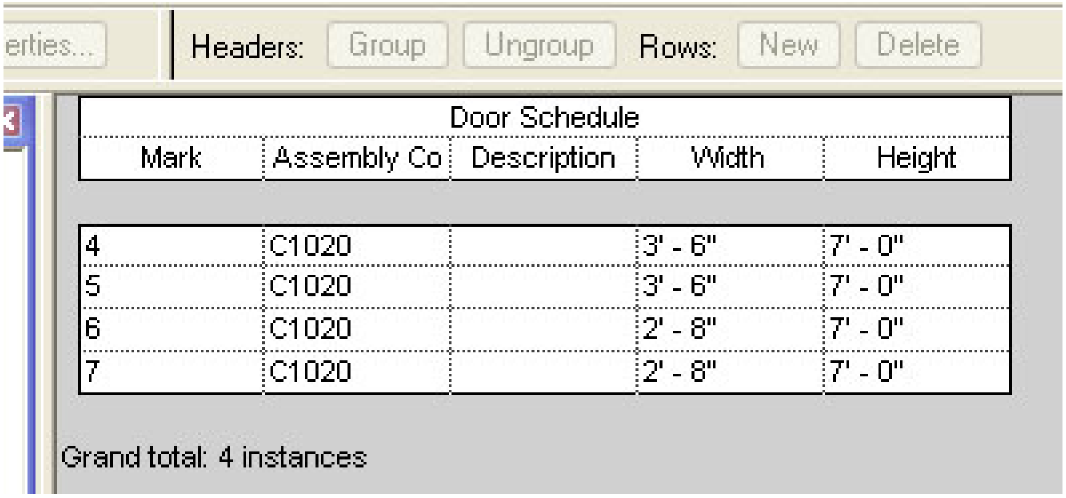


Figure 4-12 Restrooms' doors before editing



Door Schedule				
Mark	Assembly Co	Description	Width	Height
4	C1020		3' - 6"	7' - 0"
5	C1020		3' - 6"	7' - 0"
6	C1020		2' - 8"	7' - 0"
7	C1020		2' - 8"	7' - 0"

Grand total: 4 instances

Figure 4-13 Automatically generated doors' schedule

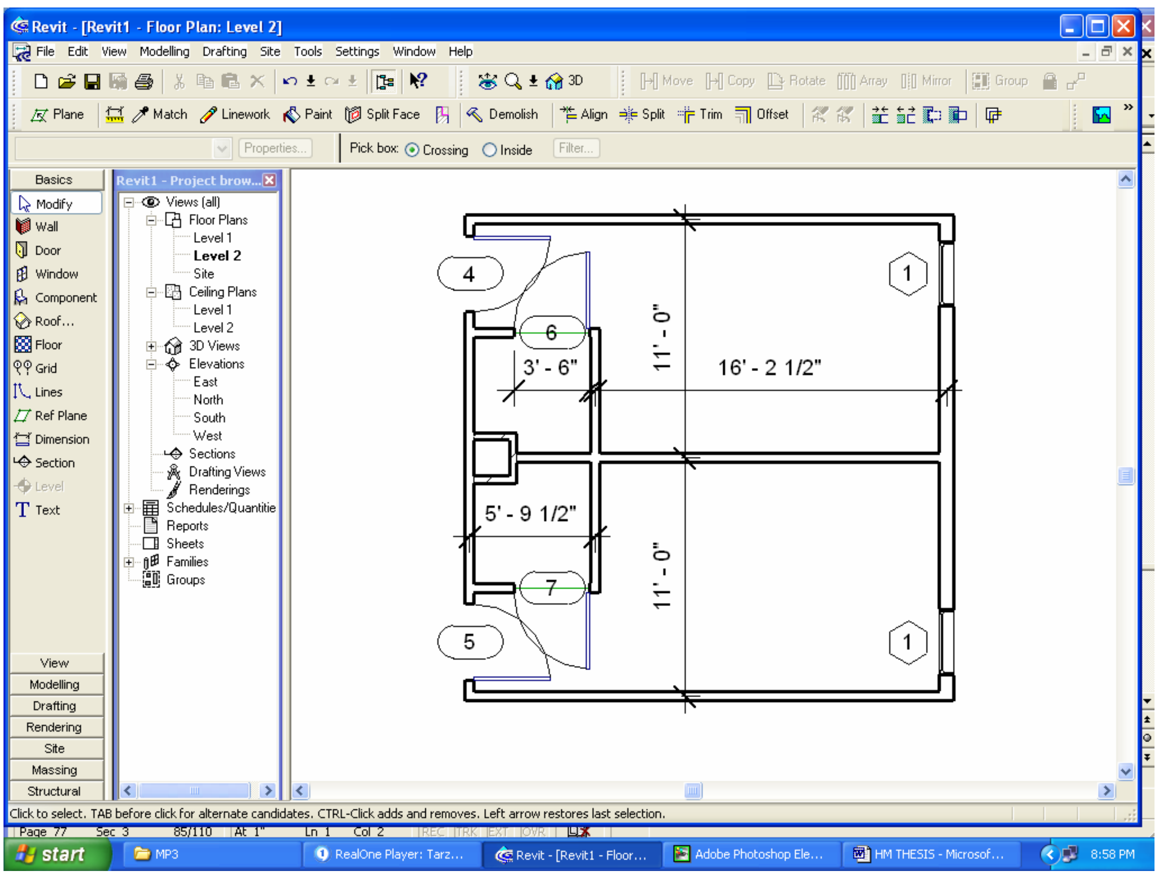
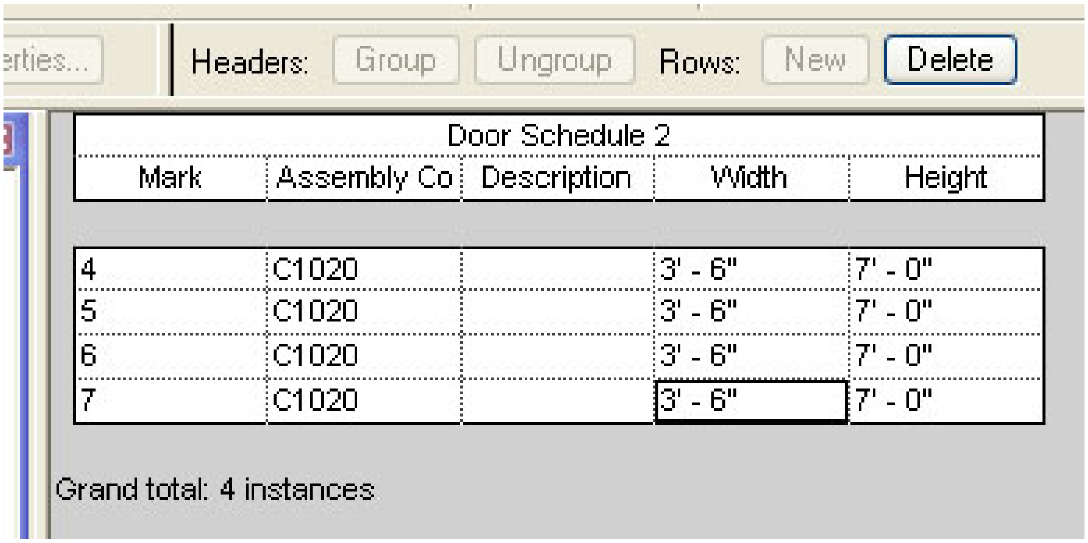


Figure 4-14 Updated drawings with the new dimensions



Mark	Assembly Co	Description	Width	Height
4	C1020		3' - 6"	7' - 0"
5	C1020		3' - 6"	7' - 0"
6	C1020		3' - 6"	7' - 0"
7	C1020		3' - 6"	7' - 0"

Figure 4-15 Automatically-updated Doors' schedule after editing the restroom's door dimensions

<u>Simulation of Inter-disciplinary conflict</u>

Among the above-mentioned changes, those related to interdisciplinary poor coordination could have been avoided if the Revit's worksets feature had been enabled during the design. By using these worksets, the building model can be subdivided into subsets according to the building systems (Architectural, Mechanical, Structural, etc) at which all users can work collaboratively. With worksets, the parametric change engine performs the coordination work that the conventional CAD systems leave to the architect. Besides, it transmits this change to the collaborative environment while maintaining all the views, drawings, and schedules fully coordinated and parametric (R. Rundell, 2001). That means that this feature helps to manage the organizational workflow to proceed in more efficient and organized manner.

First of all, and before enabling the sharing of the project, the leader of the design team members should assign one workset for each one of them; detect each area, the bounds of the scope, and each detail that each designer will be responsible for. Each design member is then responsible for staying within the original bounds doing his own work (write, edit, view). This simple step will help to avoid many of the problems often associated with poorly coordinated design drawings, which when left uncorrected will inevitably lead to increases in costs and construction duration. This feature will “force” the interaction to take place only within the model. All team members are “forced” to communicate their decisions. In the same time the parametric technology will maintain the necessary consistency among the different views of the model (plans, sections, schedules, etc.)

Procedure

To experiment how exactly the model-based collaboration is implemented using Revit’s worksets, the following steps were executed:

- The ground floor plan of the facility was first drafted using Revit (Fig 4-16).
- The project sharing was enabled by clicking on the worksets under the file menu then by clicking ok to continue, all the existing element will move into some default worksets, at which they can be edited later.(Fig 4-17)

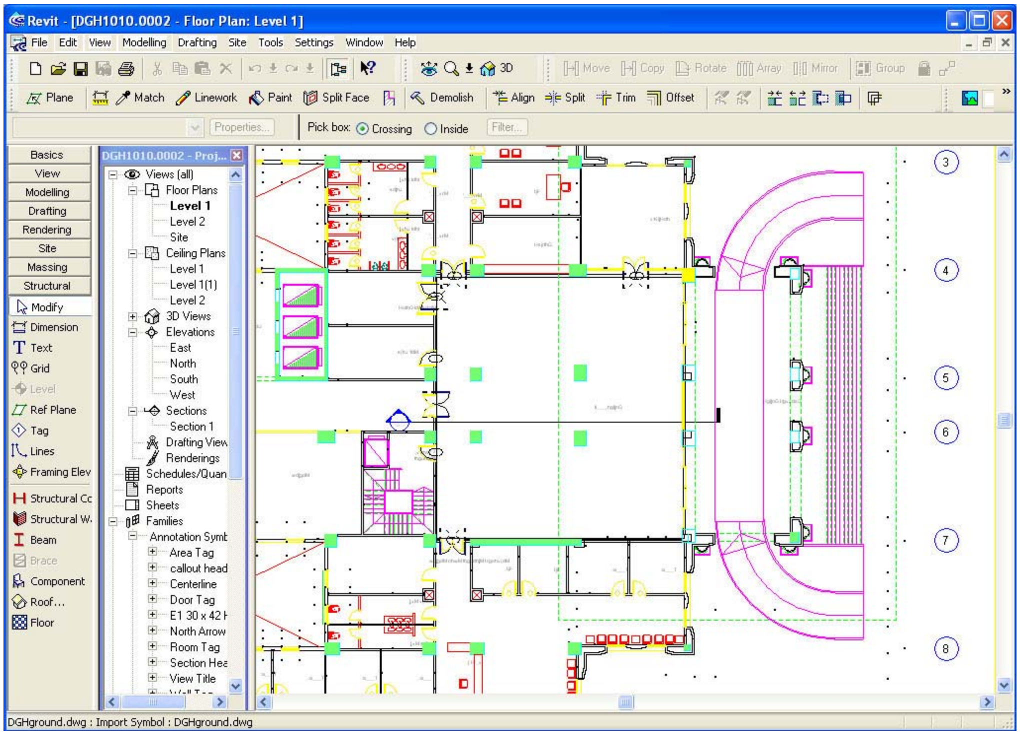


Figure 4-16 Ground floor plan of DGH hospital created using Revit

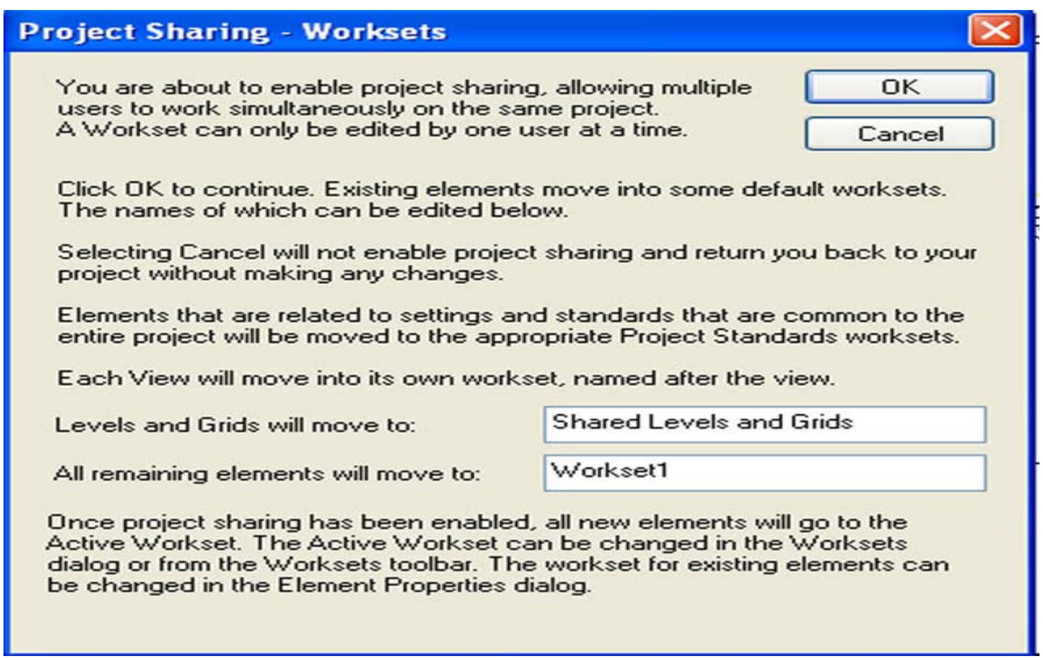


Figure 4-17 Dialogue box that displays when you first share a project through worksets

The design of the DGH project involves several design consultants; architectural, structural, mechanical, and electrical. Each of these specialties is subdivided into floors. The project worksets have been arranged as shown in Figure 4-18.

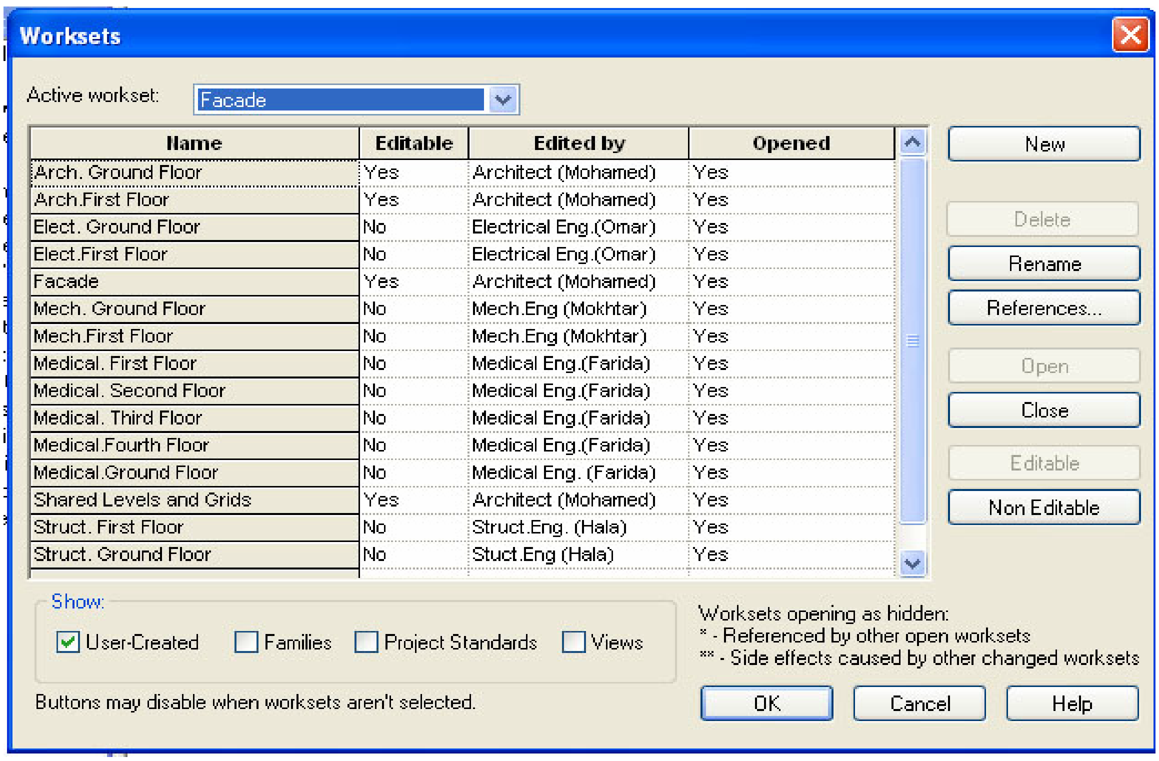


Figure 4-18 Worksets dialogue box for DGH project

In this example, the architect (Mohamed) is working on the hospital's main entrance hall of the ground floor, and he has reserved the appropriate worksets for himself. Another engineer (Mokhtar) of the mechanical consultant's office is working on the HVAC system in the same area and the structural engineer (Hala) is working on the same floor as well. The Arch. Ground Floor workset is identified as editable by the architect. He can make changes to it such as doubling the ceiling height, and save them back to the central file. In addition he may add a comment referring to this change, which will be displayed to the other design teams when they view the modified central file (Fig. 4-19, Fig. 4-20).

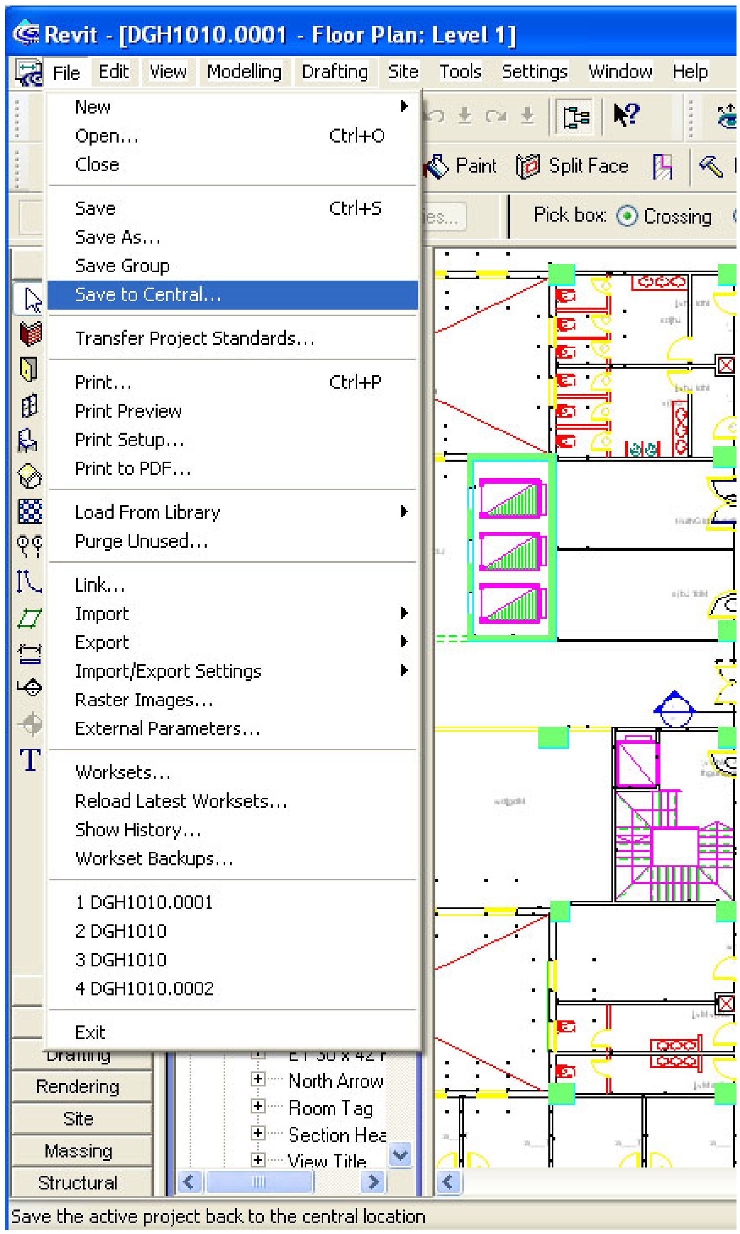


Figure 4-19 Save to central file command

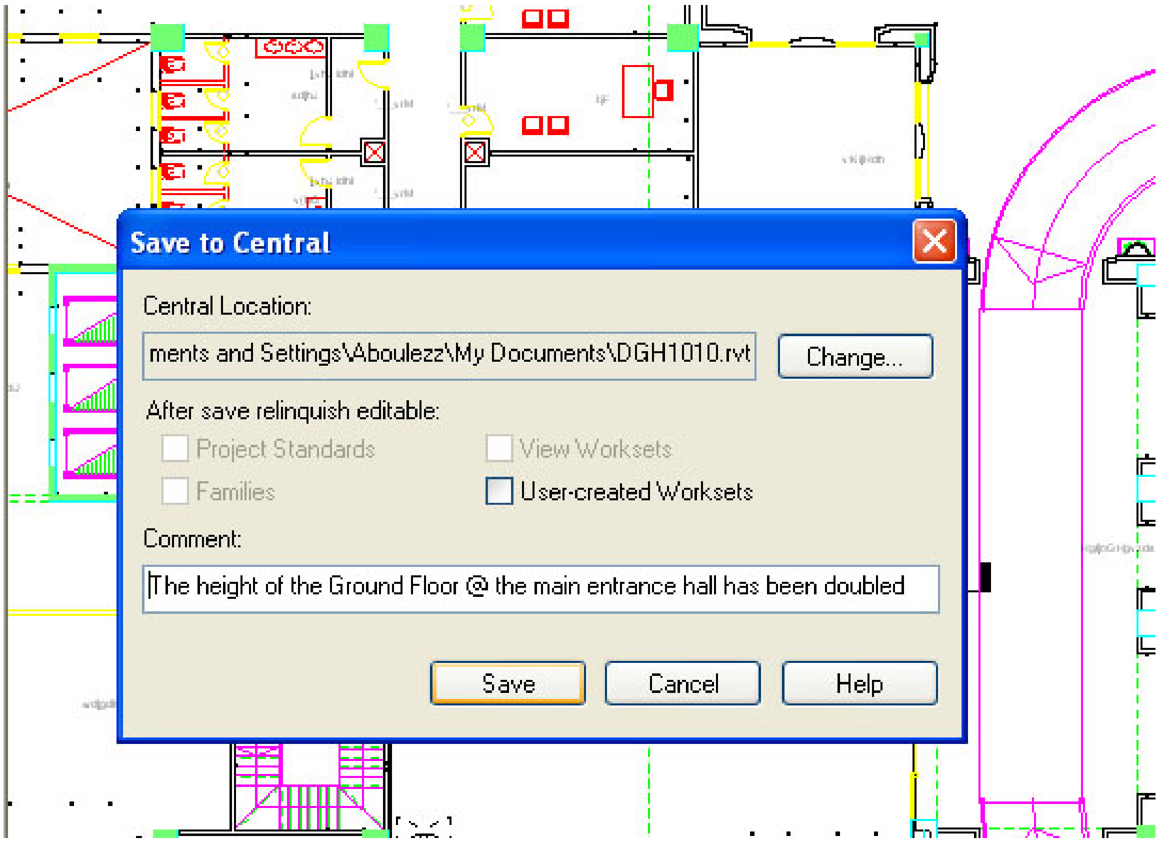


Figure 4-20 Save to central with comments dialogue box

The structural engineer as well as the mechanical engineer can work off-line on their local files; check out the latest modification by reloading the latest workset (Fig 4-21) then view the worksets history. The workset history (Fig 4-22) records all changes made to the shared model over the course of the project, along with the comments made by other team members when they saved their changes. This information display is available under the pull-down File menu, and can be exported to a text file for further reporting and analysis.

Both the structural engineer and the mechanical engineer can modify their designs accordingly based on the change that was done by the architect, then save them back to the central file.

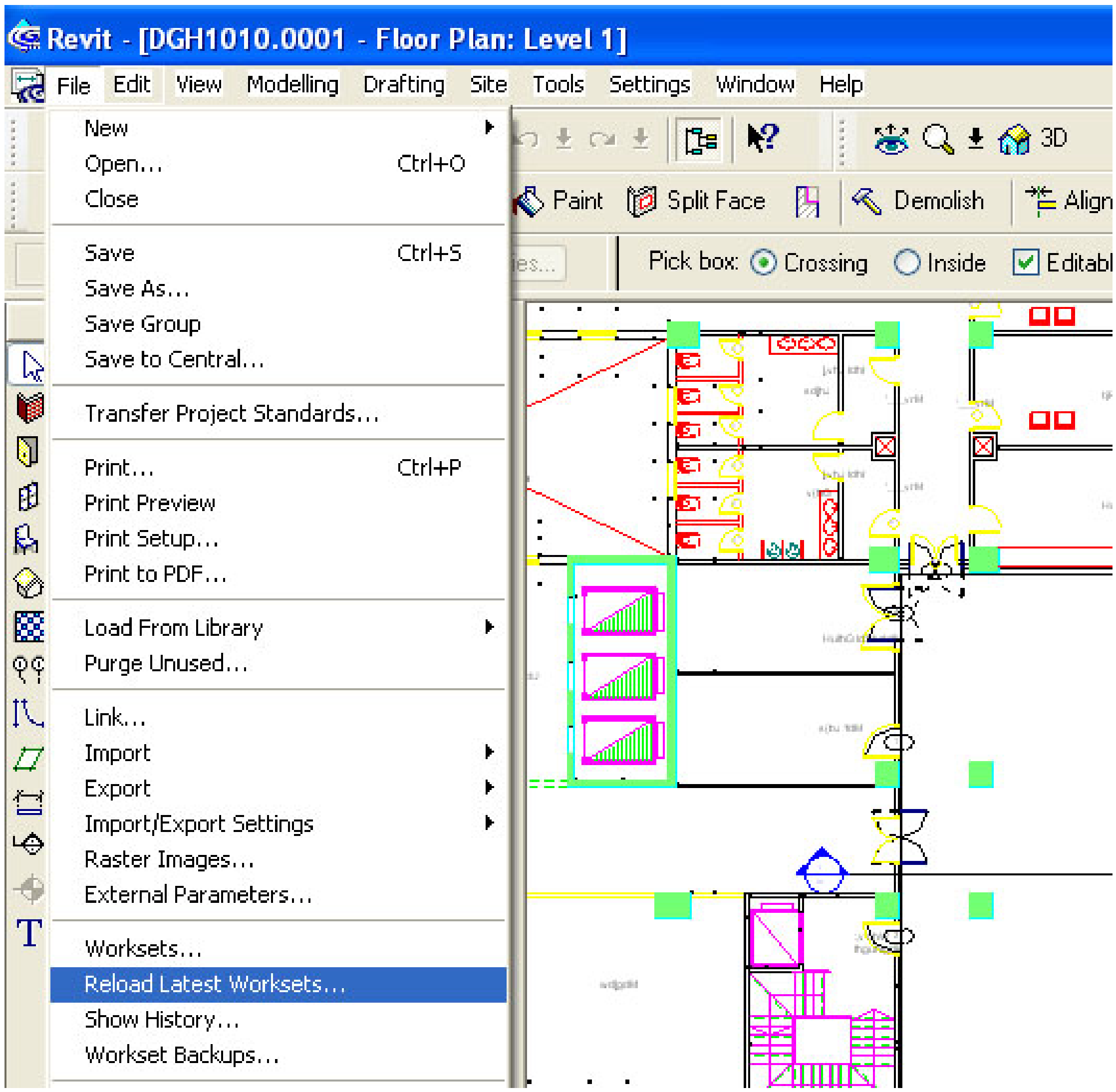


Figure 4-21 Reload Latest Worksets Command

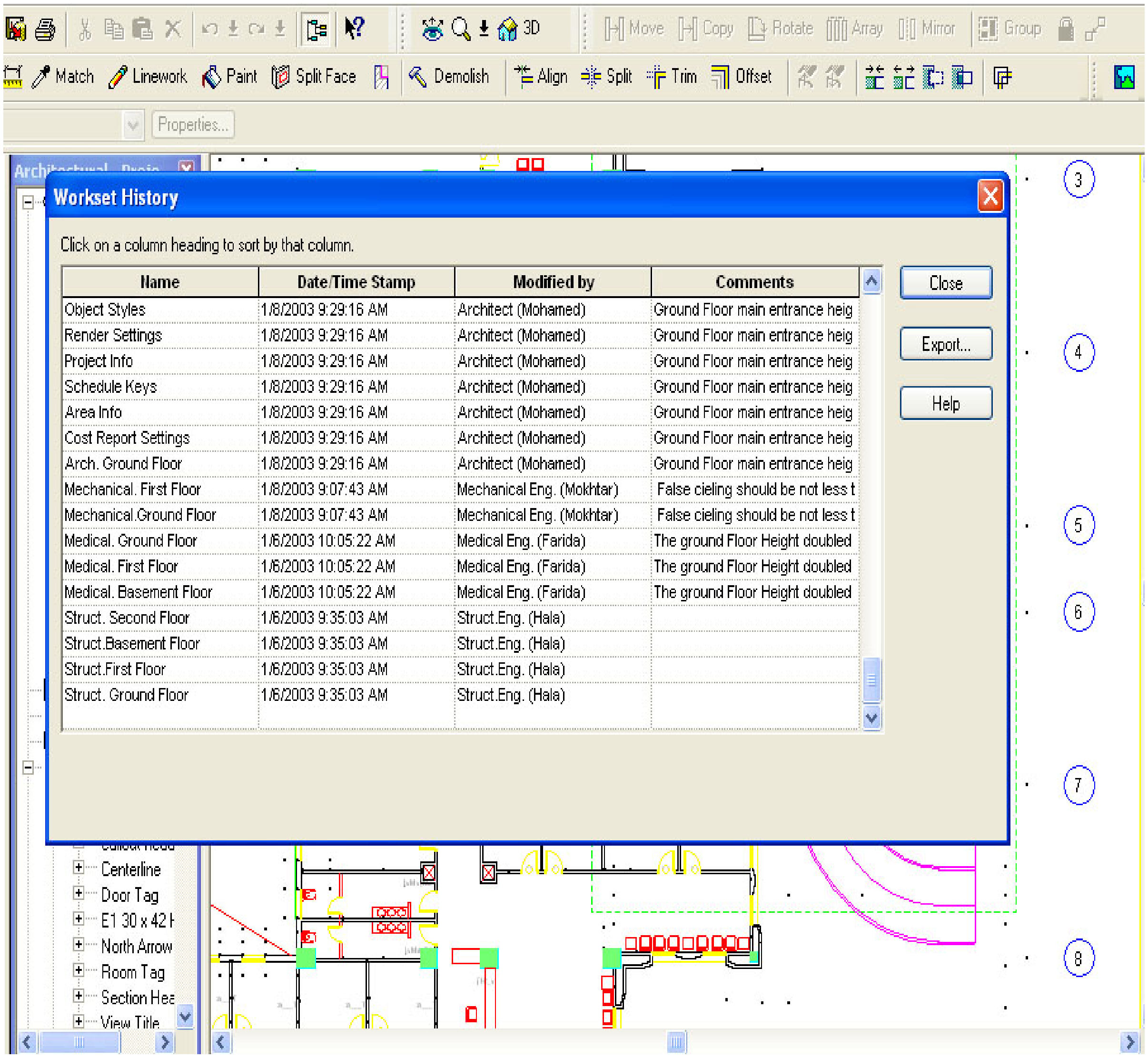


Figure 4-22 Worksets history

Revit will then propagate changes made to the whole model and makes the necessary coordination. If one of the users tried to make a change to a workset that is editable by another user, a warning message will pop up to identify that this workset is not editable. If this user tried to make it editable, another warning will appear (Fig 4-23).

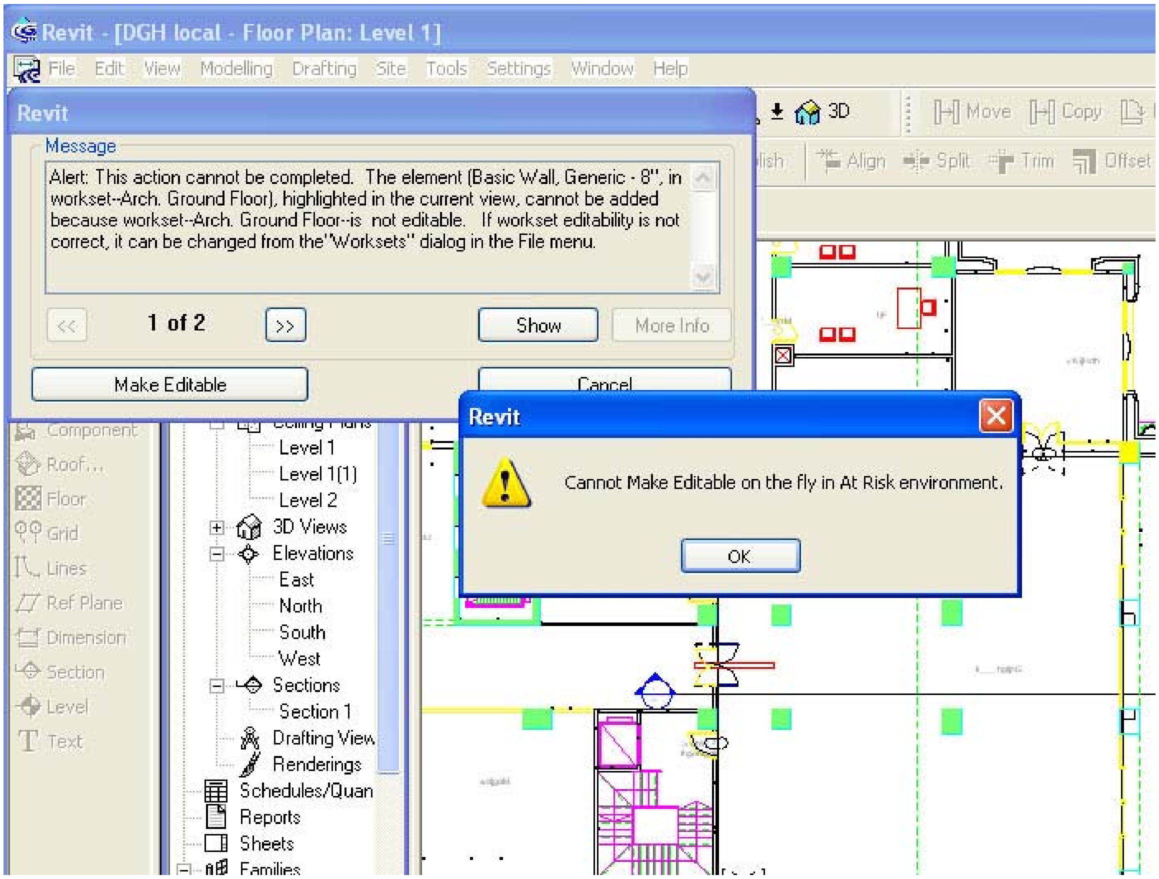


Figure 4-23 Warning message

In contrast to a drawing file–based environment, where the architect changes should be tracked through each drawing file and each file should be updated manually, in the model-based environment the Revit's parametric change engine takes care of these updates and propagates them to all views since they are all multiple representations of the same model.

The Workset function is similar to the AutoCAD's external reference capability, but with the additional ability to automatically propagate and coordinate changes between designers.

After reviewing the project's workflow model, investigating the design documents of the project, and locating the design changes that happened due to design errors and omissions, it was found that most of them were due to the poor coordinated working environment, which leads to improper handling of the project information and many design conflicts between different design trades. The reason for that was the way the design information has been exchanged during the project. The analysis of the project workflow model revealed that there were some deficiencies in the coordination process between the interdependent design disciplines.

In theory, if these drawings would have been generated using Revit, the owner would have saved 1.9% added cost and 90 days added time by avoiding change orders errors and omissions.

5 SURVEY

The development of the survey was to obtain data beyond the data-point of the case study on the average percentage of change orders (%COs) in construction projects, average percentage of change orders due to errors and omissions (%E&Os), and average percentage of E&Os due poor coordination. The survey targeted design organizations, for the reason that they are involved in "days-in and days-out" in the design process. In addition the author wanted to know what is the extent and the type of CAD packages' impact on the design documents production of these firms.

5.1 Content of the survey

The questionnaire was divided into four sections; the first part defined the respondent's profile. It contained general questions about the respondent's years of experience in the construction industry, his/her involvement, and the type of projects: public or private.

The second section was related to change orders, it included questions about the percentage of change orders in their projects, the percentage of errors and omissions resulting in change orders, and the percentage of those change orders related to errors and omissions due to poor coordination of different design disciplines.

The third part of the survey questions was related to CAD packages used by the respondents. It asked how long they have been using them, and how the coordination process between different designers was impacted by the use of these packages.

The fourth part of the survey was related to the use and familiarity of the parametric building model. The first question asked if they were considering using the 3D parametric building model. The other three questions were to know if the respondent is using the 3D parametric building model, and if so, how does this affect the productivity rate and the percentage of change orders due to errors and omissions. Finally, the respondent had to report problems (if any) while using the parametric building modeler.

A copy of the survey is in Appendix B.

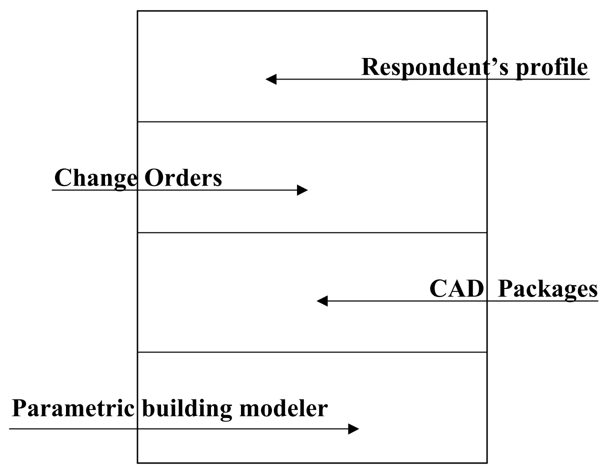


Figure 5-1 Schematic design of the survey

5.2 Response rate

The response rate in the first week after sending the survey was about 5%. A second trial was sent to the organizations that didn't respond to the first trial. An additional 5 responses were obtained (5%). Together, the first and second trials yielded a total of 10% of the ENR mailing list (10 responses) in two weeks period.

Due to the tight time frame of this survey, and to increase the % of the response rate, the author decided to post a thread discussion in the Revit's on-line users group, an on-line professionals' group that answers questions, researches products or debates issues. They were invited to respond to the survey. However, this sample was biased because these individuals are aware or familiar with Revit's parametric building model. This effort reached an additional 24 potential respondents in two weeks for a total of 53% of the total potential responses. In the mean time an additional 11 responses were received from the ENR group, which increased the total number of respondents to reach 45. A list of the responses is provided in Appendix C.

5.3 Survey results

Most of the respondents who answered the survey hold design career profession. Of these respondents, 60% of them (27 response) identified themselves as architects, 16% were project managers (7 responses), 7% were civil engineers (3 responses) and the last category was 17%, they identified themselves as others (8 responses). (Fig 5-2)

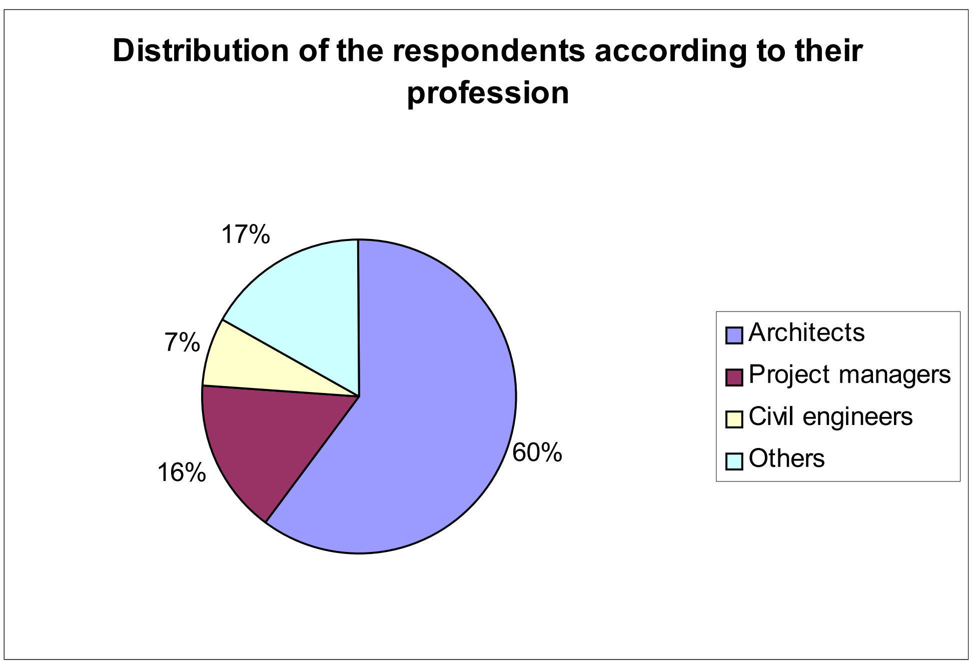


Figure 5-2 Distribution of the respondents according to their profession

The expertise of those respondents according to the projects they are involved in, whether they are public or private projects, and the number of years they are practicing their profession are shown below in Figure 5-3 and Figure 5-4.

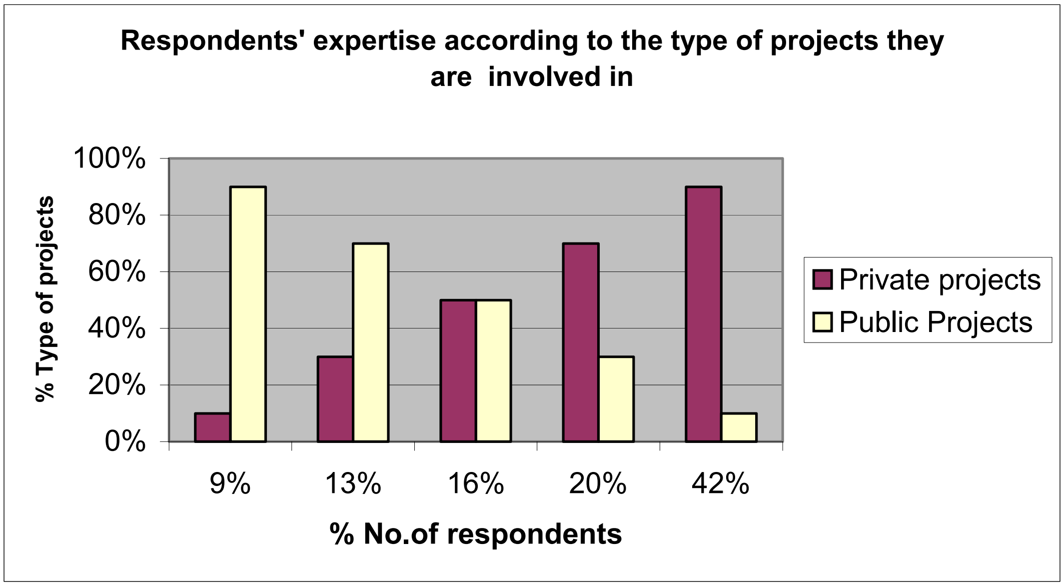


Figure 5-3 % distribution between private & public projects

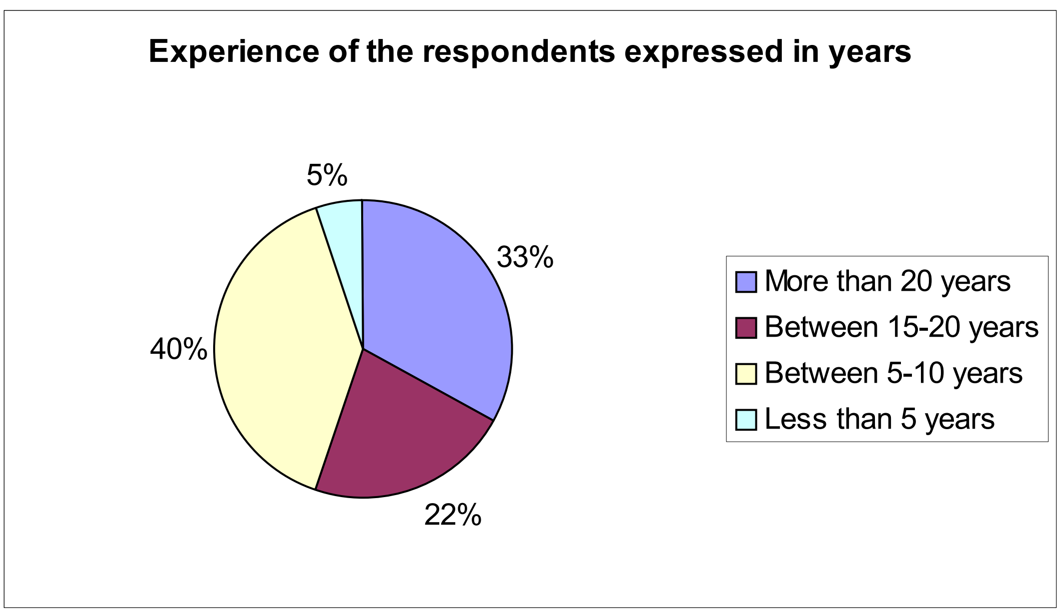


Figure 5-4 Experience of the respondents

Regarding the change orders questions, the first question was about the average percentage of change orders in their projects, 47% of the respondents replied that it ranges between 0-10%, 29% said that this percentage lays between 11-20%, equal number of them approximately 9% replied that it range between 21-30% or 31-40%, and the remainder 6% said that it is over 40% (Fig 5-5). These responses yielded a weighted average of 16%. This percentage was calculated as follows:

% Weighted average change orders = 0.47 x 5% + 0.29 x 15% + 0.09 x 25%

+ 0.09 x 35% + 0.06 x 70% = 16.3%

The respondents commented that the percentage of change orders depends on the type of project whether it's a renovation project that involves unforeseen conditions, or it's a new one. Some of them referred their occurrence to owner initiation or to the design coordination issue. Actually, the respondents' comments about the causes of change orders accord with previously executed research mentioned in section 1.1 of this report.

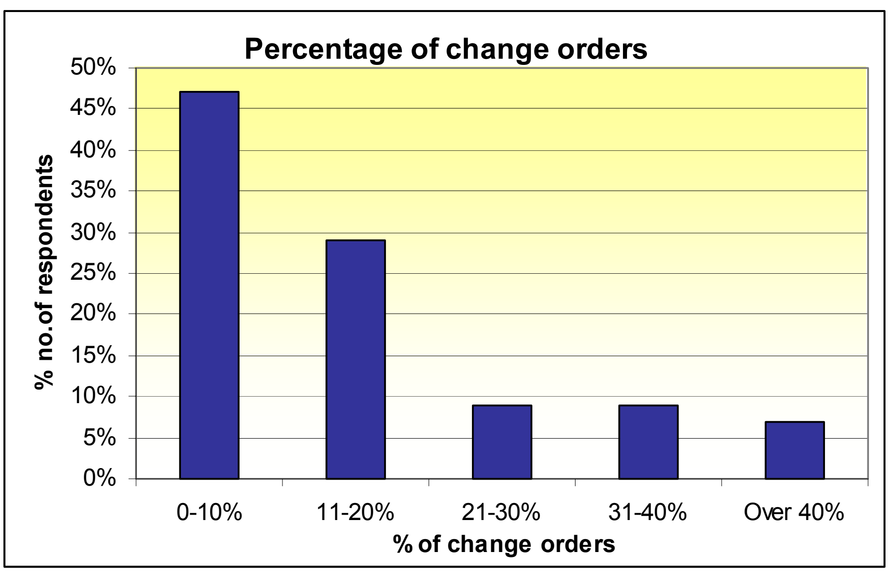


Figure 5-5 Percentage of total change orders

With respect to the change orders due to errors and omissions between the design drawings, almost 74% of them replied that it ranges between 0-10%, 7% said that it is between 11-20, 14% responded that it lays between 21-30%, while as 5% said that it is from 31-40% (Fig. 5-6). The respondents mentioned that errors and omissions are mainly resulting from poor coordination. They also added that these errors and omissions could be generated by the lack of the designer's knowledge. The percentage of errors and omissions due to poor coordination is presented in (Fig. 5-7). The responses related to this question showed that the average percentage of E&Os change orders is 10%. This percentage was calculated as follows:

% Weighted average = 0.74 x 5% + 0.07 x 15% + 0.14 x 25% + 0.05 x 35% = 10%

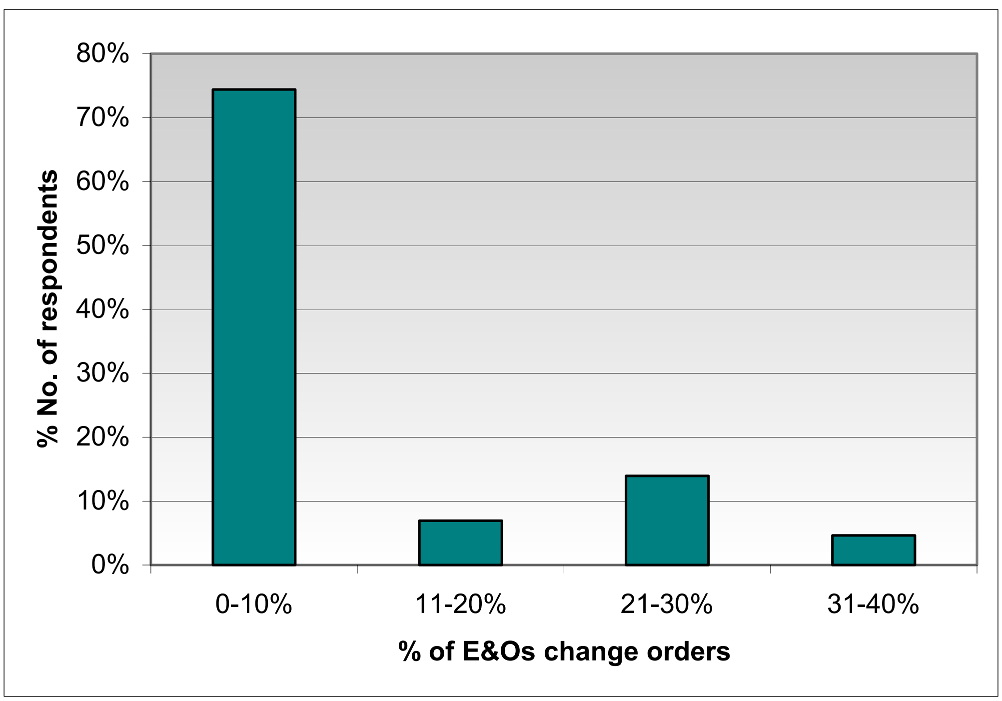


Figure 5-6 Percentage of errors and omissions change orders

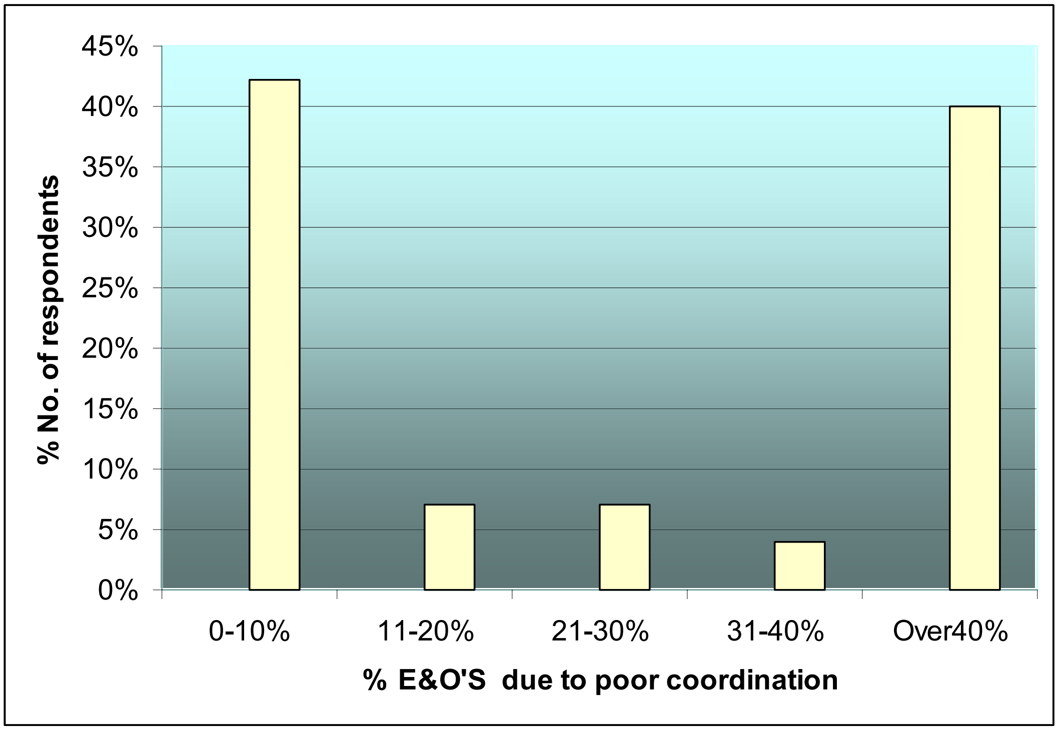


Figure 5-7 Percentage of the E&Os change orders due to poor coordination

The response to the CAD packages they use was as follows:

Table 5-1 Distribution of different CAD packages among respondents of the ENR's group

CAD Package	**% No. of respondents**
2D drafting	59%
3D modeling	41%
3D Parametric modeling	0%

Table 5-2 Distribution of different CAD packages among respondents of the Revit users' group

CAD Package	% No. of respondents
2D drafting	0%
3D modeling	0%
3D Parametric modeling	100%

Because Revit software was newly introduced to the market in 1997, as mentioned before in Section 2.3.1.3.1, the analysis of the data obtained from the top 100 ENR design firms showed that the parametric building model is not yet utilized. However, it is widely spread among a large number of smaller design firms (Revit on-line users' group). A list of these firms is provided in Appendix C.

The analysis of the responses of the ENR design firms and the Revit users' group regarding the effect of the use of CAD packages in the design showed different patterns. In the ENR design firms sample 66% of the respondents expressed that the CAD packages (2D drafting, 3D modeling) they are using have minor to no impact on the coordination process. While 24% and 10% articulated that the impact was moderate to major respectively. On the other hand, in the Revit users' group, who are using the parametric building modeling, 63% described the impact as extreme to major, 29% as moderate, and 8% as minor. This is illustrated in the Figures 5-8 and 5-9.

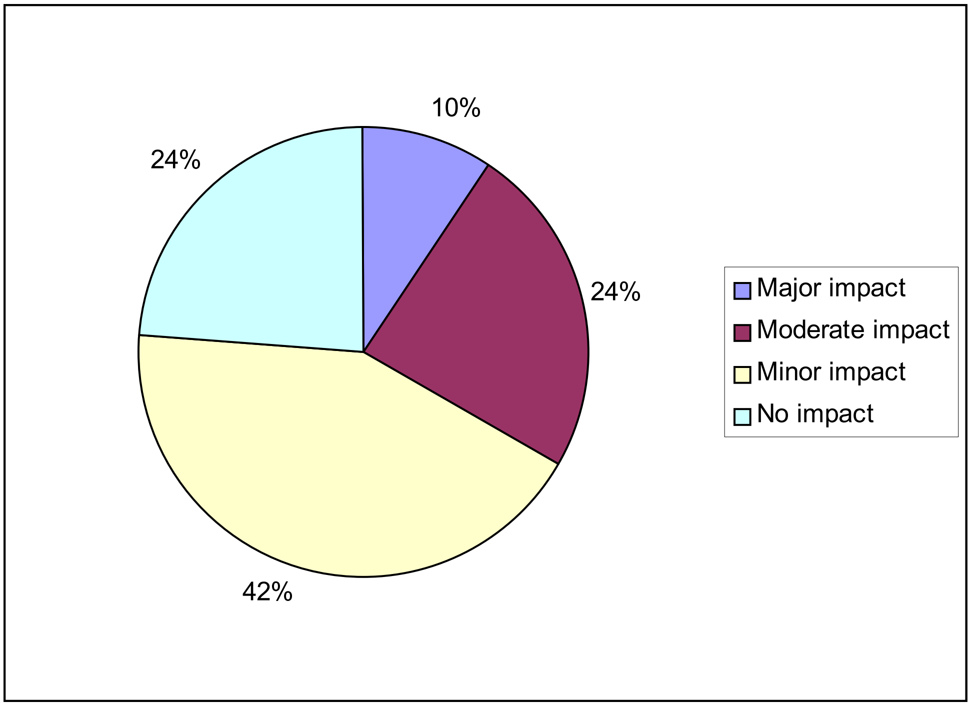


Figure 5-8The effect of the use of CAD packages on the coordination of design drawings (ENR design firms)

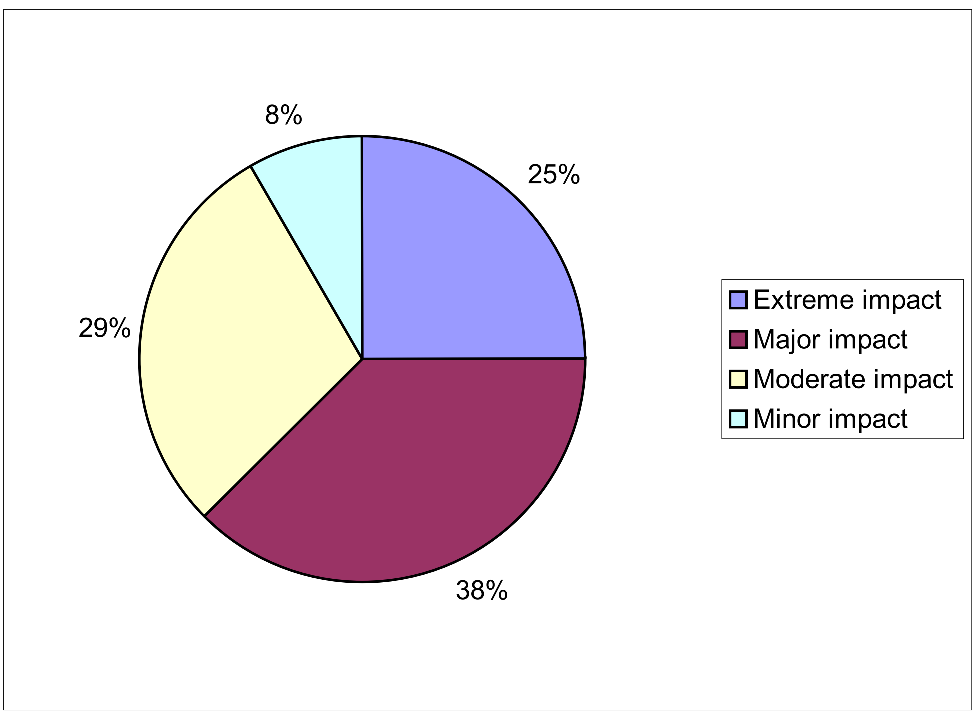


Figure 5-9 The effect of the use of CAD packages on the coordination of design drawings (Revit users' group)

In the parametric building model questions, almost half of the respondents who don't use the 3D parametric modeling in generating the design drawings intend to change to use it instead of 2D drafting or 3D modeling, 14% said they are not going to change, and the rest did not respond. To investigate the impact of the use of the 3D building modeling on the productivity, only the results obtained from the Revit users were considered. 77% of them replied that the use of the parametric building model increased their productivity to a significant extent (Extreme impact and Major impact), 23 % said that it has moderate impact (Fig 5-10)

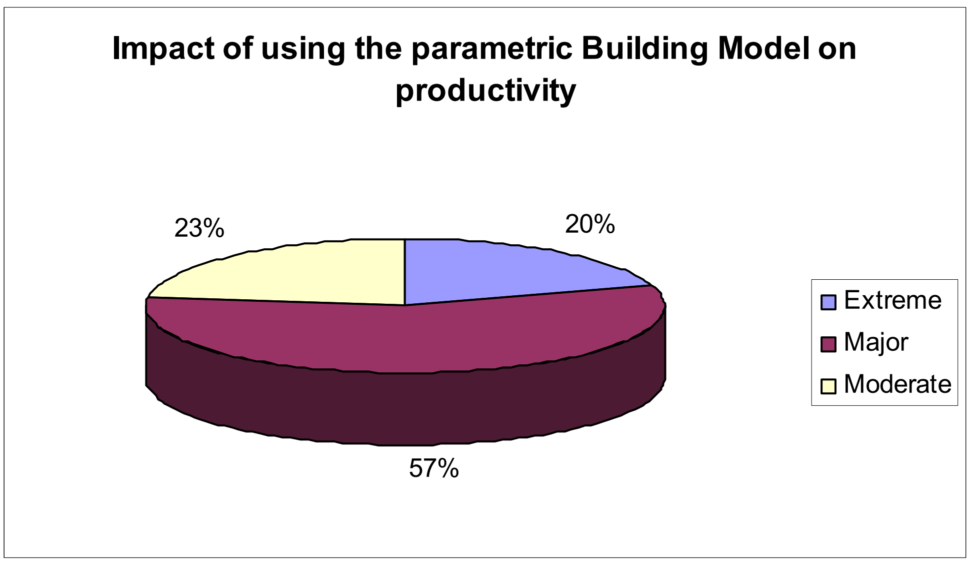


Figure 5-10 Impact of using parametric building model on productivity

As far as the impact of using 3D building model on errors and omissions change orders, the responses showed that 50 % of its users experienced extreme or major difference, 35% experienced moderate impact, whilst the other 15% said it has minor impact (Fig 5-11).

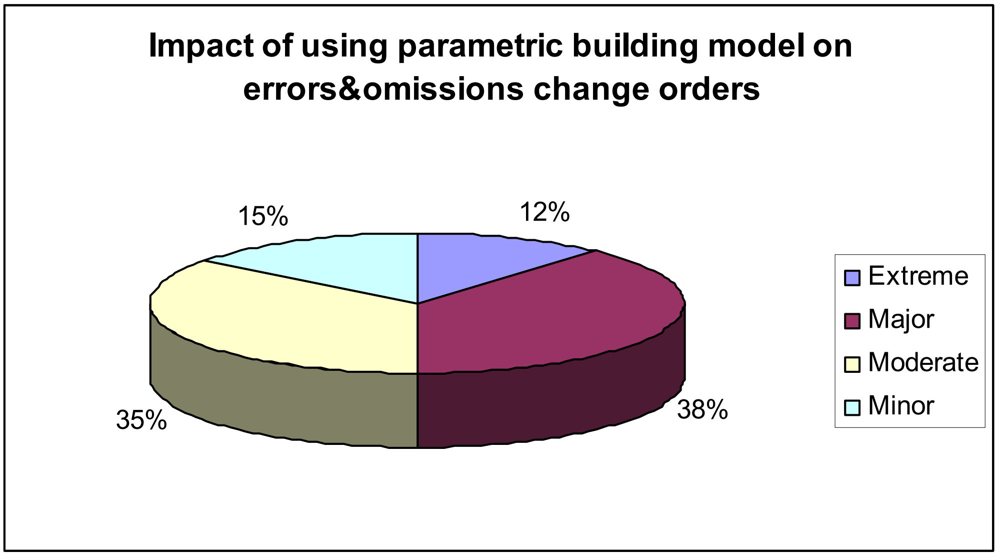


Figure 5-11 Impact of parametric building model on errors & omissions change orders

Regarding the problems the respondents experience with the parametric building model some of the comments were as follows:

Design firms comments ”Non-Revit users”

- Current parametric models could be difficult to use for major process facilities as they were created for vertical construction more than process facilities.
- The main problem is getting technicians trained and proficient in 3D and getting project managers and clients accepting that it will not cost more money and will actually result in higher quality and lower change orders due to the built-in interference management software that we use.

Revit’s users group comments

- There are some program limitations.
- Needs a fast computer to run.(hardware)

- Making the software work like the building process or being constrained by the abilities of the software.
- Not efficient for irregular structures

5.4 Survey Conclusion

From the analysis of the survey results, it was found that three fourth of the respondents were architects with a good experience in the engineering design profession. Most of them are involved in private projects rather than pubic projects. Their reply revealed that the weighted average percentage of cost increase due to change orders is 16%, and that the weighted average percentage of added cost due to errors and omissions change orders is 10%. On the average, 35% of these errors and omissions result from poor coordination among design documents. The analysis of the responses of the ENR design firms and the Revit users' group regarding the effect of the use of CAD packages in the design showed different patterns. In the ENR design firms sample 66% of the respondents expressed that the CAD packages (2D drafting, 3D modeling) they are using have minor to no impact on the coordination process. While 24% and 10% articulated that the impact was moderate to major respectively. On the other hand, in the Revit users' group, who are using the parametric building modeling, 63% described the impact as extreme to major, 29% as moderate, and 8% as minor. Regarding the impact of the use of the parametric building model on the productivity issue, 77% , namely those who had experience working with the software (Revit users' group), expressed that it has enhanced their productivity dramatically (extreme to major impact). As far as its impact on the coordination process, their responses replicated that it has been enhanced to a certain extent, 50% said that it has extreme to major impact, 35% said it has moderate impact, and the other 15% went with the minor impact.

From all above, it can be concluded that the designers that are using the parametric building technology in their projects have started to gain some benefits through enhanced productivity and better coordination throughout the design documents. This improved coordination can help them to manage the design documents more efficiently, hence reduce the errors and omissions change orders.

Actually, the results of the survey support the hypothesis of this study that by introducing this model-based software in construction projects, the power of coordinating the information across the entire design has been demonstrated. 63% of the Revit users' group expressed that the use of the parametric building modeling has extreme to major impact, while only 10% of the non-Revit users, but who actually use 3D modeling referred to the impact as major.

However, the respondents expressed that they do have some problems associated with the use of this model such as some limitations in the software or its inability to adopt the uniqueness nature of the construction projects. They also mentioned that it is mainly suitable for vertical construction rather than horizontal construction. Yet, these problems are expected since this model-based software is newly introduced in the construction industry, and it will be tackled in the new versions of the packages.

Finally, it is observed that there is a correlation between the percentage of the change orders found in the case study (6%) and the percentage obtained from the respondents' replies (47% of them said that it is from (0-10%)). Also, the percentage of change orders due to errors & omissions was 2% in the case study, which, falls in the data range of the survey (74% of the respondents replied that it is from (0-10%)). Regarding the percentage of the E&Os due to poor coordination, the case study analysis yielded that 100% of the change orders due errors and omissions were due to poor coordination. While 40% of the survey respondents claimed that over 40% of E&Os are due to poor coordination.

6 CONCLUSION AND FUTURE WORK

6.1 Conclusions

This research explored the extent to which change orders resulting from errors and omissions in the design documents are caused primarily by poor coordination and communications. It also determined the extent to which the use of the concept of the 3D parametric building model can be used to minimize or eliminate E&Os.

Different tools and concepts had been used in developing this research. The literature related to the design changes implementation process, and the different workflow models of the design information was first reviewed. A case study was presented to compare the traditional approach to create construction documents with the use of 3D building model. Finally, a survey was conducted to verify the hypothesis of this research.

The literature review pointed out that design changes are usually originated, among others, from approved scope changes or due to design errors and omissions. These errors and omissions are typically manifested in terms of incorrect or inconsistent dimensions and layouts in the construction documents or by the lack of timely and correct information that it is needed to build the project or to meet the code requirements. The main source of these E&Os is the poor coordination and communication among the many parties involved in the design process.

This lack of coordination is mainly resulting from two reasons; first, the way the design information is transferred among the project different participants in order to avoid any conflicts and incompatibilities between their specialties. Secondly, the technology they use to develop these drawings. This technology will be an ideal tool for producing design drawings if it guarantees the effective sharing and collaboration of design information between the different design personnel and maintaining consistency between the different representations of any design element. Techniques such as manual drafting and 2D conventional CAD do not satisfy the previous requirements as effective tools, due to the fact that every drawing is considered as a separate entity, or it creates multiple representations of the design object. The design change process should involve effective means of sharing knowledge through appropriate presentation of the building solution. Therefore, the model-based approach seems to provide an improved way to enhance the efficiency throughout the process of building design, construction and management. It helps the design professionals to communicate, coordinate and manage the design information.

The literature review also revealed that the way professionals in the architectural, engineering, and construction (A/E/C) firms interact, collaborate, and communicate throughout the different stages of the construction project's life cycle can have a profound impact on it's success to meet the planned expectations. For that reason, the workflow management is an essential technique for providing effectiveness and success of any design changes and consequently to the whole project. Neglecting this process will lead the project participants to compromise and not to obtain the required accuracy.

In addition, the review of the published methods that quantify the impact of change orders indicated that these methods can not be used in this research for the following reasons: The CII and the Hanna methods used electrical and mechanical projects based purely on work-hours and not by cost (dollars) because of their labor-intensive nature, where the labor cost component of these two industries represents 40 % to 50% of their total costs. Another problem with these studies is that it is difficult to validate their developed models with high classification and prediction accuracy for new cases because of the low R^2 value (quality of regression model). There are still other factors, which significantly impact productivity, that are correlated in nonlinear fashion. Also, many of them are qualitative rather than quantitative in nature. Usually, regression analysis has limited success when dealing with many qualitative or “noisy” input variables (Lee et al., 2002). Similarly, Leonard method could not be used in this study, because the samples he used to develop his model were taken from extreme cases that went to the claims stage. These extreme cases do not express the general conditions of a typical project.

Therefore, for the purpose of this study, the impact was measured by the percentage cost increase due to change orders caused by E&Os and the number of days lost or added to the project duration.

Both the case study and the survey results seem to support the hypothesis of this study. In the case study analysis, the percentage of added cost due to change orders was 6% of the initial cost. Approximately 33% (E&Os were 2% of the initial cost) of this increased cost was due to E&Os change orders. All of the observed E&Os presented were due to poor coordination, either between the design drawings within the same discipline or between one design discipline, namely architectural, and other disciplines such as structural, mechanical, and electrical. The first set of errors that occurred within the same discipline could have been taken care of automatically with the help of the parametric capabilities of the software, which maintains the consistency of each design element all the way through the different documents, since they are just several views of the same model. The other set of the errors could have been tackled by coordinating the inter-relationships of the same design elements between the different design personnel. This could be achieved by sharing the design information and keeping it updated by using the "workset" feature of the software. Revit's worksets can be used to propagate and coordinate changes between designers. Using this feature allow team members to add elements to their worksets and see the latest changes done by other team members to make sure that the project design is progressing in a well-coordinated manner.

The results of the survey showed that the weighted average percentage of cost increase due to change orders is 16%. From which 10% of these 16% added cost to the project is directly due E&Os change orders. On the average, 35% of these errors and omissions result from poor coordination among design documents. More than 50% of the respondents were designers who had experienced working with Revit as a parametric building model technology in their projects. They expressed that the use of the 3D parametric building model has a significant impact on productivity and on improving the coordination of the design process. This improved coordination can help them to manage the design documents more efficiently, hence reducing the errors and omissions change orders. Although the benefits of moving to the 3D parametric building model are encouraging, some respondents to the survey claimed that it still has to adopt all types of projects with necessary details, the users need while building their model. Besides, the model needs some improvement in other building disciplines beside the architectural.

This study strongly suggests that the use of the parametric building model can dramatically improve the state-of-the-art. It allows the design team members to spend more time on the tasks that add more value to the project design. Less time is spent on tedious coordination with other disciplines' drawings in contrast to the use of the conventional CAD applications. By using the 3D parametric building model, designers can perform "What If" inquiries to find the impact of different solutions to a problem. Moreover, simulating the consequences of a design idea can avoid unexpected construction surprises.

6.2 Future work

The 3 D building model as a newly introduced concept to the A/E/C industry provides a wide platform for future research. The other capabilities of the model, not reviewed in detail in this research to generate design documents can be investigated. For example, assessing the capabilities of the model in the production of sound quality design documents, the economics of the use of the software for both the short and long terms, and finally the visualization capabilities of the software and how they enhance communicating with the owner in order to meet, or even exceed his expectations, can be investigated.

Further future work can also include exploring a case study to observe the interaction and coordination of the design team in real projects when Revit is used, as well as the need to investigate other factors that cause E&Os other than poor coordination.

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Appendix A The survey's invitation letter

Dear Sirs:

I am a graduate student in the Civil & Environmental Department at Worcester Polytechnic Institute Worcester, Massachusetts. I am conducting a study for my Master of Science thesis on " Assessing the capabilities of the parametric building model in managing change orders", More specific I am interested in learning the extent to which a 3D CAD software may help to reduce
change orders due to design errors and omissions. My thesis advisor is Prof. Guillermo Salazar http://users.wpi.edu/~salazar/
I am asking for your help by filling out and submitting the questionnaire available on the web at:
http://users.wpi.edu/~hnmokbel/survey.html
The survey consists of 14 questions, so it should take almost 10 minutes to complete and submit the form.
Your prompt response will be important to the success of my research and I hope you will take the time to share your ideas and submit your answers. I will be glad to share the results of the survey with those who include their e-mail address.

Thank you!

If you have any problems or questions about the survey please feel free to contact me by e-mail or by phone (hnmokbel@wpi.edu / (508) 831 5011).

Hala Mokbel
CEE Department @ WPI
hnmokbel@wpi.edu
Tel:508-831-5011

Appendix B The Survey Form

Assessing The Parametric Building Model Capabilities

A Survey for a Research Project by:

Hala Mokbel

Teaching Assistant @ CEE Department

Worcester Polytechnic Institute

Experience in the Construction industry

1. Which of the following typically describes your role in a construction project?

2. Which of the following better reflects your experience in the construction industry?

3. Your experience has been developed by working mostly in:

Private Projects Public Projects

Change Orders Questions:

4. On average, what is the percentage of change orders in projects?

Comments

5. On average, what is the percentage of total change orders in a project resulting from errors & omissions?

Comments

6. On average, what percent of change orders due to errors & omissions are due to poor coordination of different design disciplines?

Comments

CAD Software Package Questions:

7. Which design package do you use to generate design drawings?

8. How long have you been using this package?

9. How does CAD software impact the coordination of different design disciplines?

Parametric Building Model Questions:

10. If you are using CAD package as a drafting tool are you considering changing to 3D parametric buiding model?

11. If you are using 3D building model, how does that affect your productivity?

12. If you are using 3D building model, how does that impact errors and omissions change orders?

13. What problems do you experience while using this building modeler?

14. Comments/Recommendations

Could we contact you for further information in relation to this research? If possible, please fill out the followings:

Name

Department Company

Telephone Email

submit Form Clear Form

Appendix C Survey Responses

	Which of the following typically describes your role in a construction project?
1	other
2	Project manager
3	Project manager
4	Civil engineer
5	Civil engineer
6	Architect
7	other
8	Architect
9	Architect
10	Architect
11	other
12	other
13	Project manager
14	Architect
15	other
16	Architect
17	Architect
18	Architect
19	Architect
20	Architect
21	Architect
22	Architect
23	Architect
24	other
25	Project manager
26	Architect
27	Architect
28	Architect
29	Architect
30	Architect
31	Architect
32	Architect
33	Architect
34	Architect
35	Architect
36	Civil engineer
37	Architect
38	other
39	other
40	Architect
41	Project manager
42	Architect
43	Project manager
44	Architect
45	Project manager

	Which of the following better reflects your experience in the construction industry?
1	More than 20 years
2	More than 20 years
3	More than 20 years
4	between 15-20 years
5	between 15-20 years
6	More than 20 years
7	between 15-20 years
8	More than 20 years
9	More than 20 years
10	Less than 5 years
11	between 5-10 years
12	between 5-10 years
13	between 5-10 years
14	between 5-10 years
15	More than 20 years
16	between 15-20 years
17	between 5-10 years
18	between 5-10 years
19	More than 20 years
20	More than 20 years
21	between 5-10 years
22	More than 20 years
23	between 5-10 years
24	between 15-20 years
25	between 15-20 years
26	between 15-20 years
27	More than 20 years
28	between 5-10 years
29	between 15-20 years
30	More than 20 years
31	between 5-10 years
32	between 5-10 years
33	between 5-10 years
34	between 15-20 years
35	More than 20 years
36	Less than 5 years
37	between 5-10 years
38	between 15-20 years
39	between 5-10 years
40	More than 20 years
41	More than 20 years
42	between 5-10 years
43	between 5-10 years
44	between 5-10 years
45	between 5-10 years

	Your experience has been developed by working mostly in	
	Private Projects	Public Projects
1	0-20%	80-100%
2	80-100%	0-20%
3	60-80%	20-40%
4	40-60%	60-80%
5	40-60%	40-60%
6	80-100%	60-80%
7	80-100%	0-20%
8	80-100%	0-20%
9	80-100%	20-40%
10	80-100%	0-20%
11	80-100%	0-20%
12	80-100%	0-20%
13	0-20%	80-100%
14	0-20%	80-100%
15	80-100%	0-20%
16	80-100%	0-20%
17	20-40%	60-80%
18	60-80%	20-40%
19	20-40%	60-80%
20	20-40%	60-80%
21	80-100%	0-20%
22	60-80%	20-40%
23	60-80%	0-20%
24	80-100%	0-20%
25	80-100%	0-20%
26	20-40%	60-80%
27	80-100%	0-20%
28	80-100%	0-20%
29	60-80%	0-20%
30	80-100%	0-20%
31	80-100%	0-20%
32	20-40%	60-80%
33	60-80%	20-40%
34	40-60%	20-40%
35	60-80%	60-80%
36	20-40%	60-80%
37	60-80%	20-40%
38	80-100%	0-20%
39	80-100%	0-20%
40	20-40%	40-60%
41	60-80%	20-40%
42	40-60%	40-60%
43	0-20%	80-100%
44	0-20%	80-100%
45	0-20%	80-100%

	On average, what is the percentage of change orders in projects?
1	0-5%
2	0-5%
3	36-40%
4	11-15%
5	0-5%
6	16-20%
7	6-10%
8	16-20%
9	21-25%
10	16-20%
11	Over 40%
12	Over 40%
13	0-5%
14	Over 40%
15	11-15%
16	0-5%
17	21-25%
18	26-30%
19	11-15%
20	11-15%
21	16-20%
22	0-5%
23	6-10%
24	0-5%
25	6-10%
26	36-40%
27	16-20%
28	6-10%
29	6-10%
30	6-10%
31	0-5%
32	6-10%
33	31-35%
34	26-30%
35	0-5%
36	6-10%
37	6-10%
38	16-20%
39	36-40%
40	16-20%
41	16-20%
42	0-5%
43	6-10%
44	11-15%
45	6-10%

	Which design package do you use to generate design drawings?
1	2D drafting
2	2D drafting
3	2D drafting
4	3D modeling
5	3D modeling
6	3D parametric modeling
7	3D parametric modeling
8	3D parametric modeling
9	3D parametric modeling
10	3D parametric modeling
11	3D parametric modeling
12	3D parametric modeling
13	3D parametric modeling
14	3D modeling
15	3D modeling
16	2D drafting
17	3D modeling
18	3D parametric modeling
19	3D parametric modeling
20	3D parametric modeling
21	3D parametric modeling
22	3D parametric modeling
23	2D drafting
24	2D drafting
25	2D drafting
26	3D parametric modeling
27	3D modeling
28	3D parametric modeling
29	2D drafting
30	3D parametric modeling
31	3D parametric modeling
32	2D drafting
33	3D parametric modeling
34	3D parametric modeling
35	3D parametric modeling
36	3D modeling
37	3D parametric modeling
38	3D parametric modeling
39	3D modeling
40	2D drafting
41	2D drafting
42	3D modeling
43	3D parametric modeling
44	2D drafting
45	3D parametric modeling

How long have you been using this package?	How does CAD software impact the coordination of different design disciplines?
15-20 yrs	Moderate impact
5-10 yrs	Moderate impact
15-20 yrs	Minor impact
0-5 yrs	Moderate impact
0-5 yrs	Moderate impact
0-5 yrs	Major impact
0-5 yrs	Moderate impact
0-5 yrs	Minor impact
0-5 yrs	Moderate impact
0-5 yrs	Major impact
0-5 yrs	Extreme impact
5-10 yrs	Extreme impact
0-5 yrs	Major impact
5-10 yrs	Major impact
0-5 yrs	Moderate impact
15-20 yrs	Minor impact
0-5 yrs	Moderate impact
0-5 yrs	Major impact
0-5 yrs	Major impact
0-5 yrs	Major impact
0-5 yrs	No impact
0-5 yrs	Moderate impact
5-10 yrs	No impact
5-10 yrs	Major impact
0-5 yrs	Major impact
0-5 yrs	Extreme impact
5-10 yrs	Major impact
0-5 yrs	Major impact
10-15 yrs	Major impact
0-5 yrs	Extreme impact
0-5 yrs	Moderate impact
5-10 yrs	Moderate impact
0-5 yrs	Major impact
0-5 yrs	Major impact
0-5 yrs	Moderate impact
5-10 yrs	Major impact
0-5 yrs	Minor impact
0-5 yrs	Extreme impact
0-5 yrs	Moderate impact
15-20 yrs	Major impact
5-10 yrs	Major impact
5-10 yrs	Minor impact
0-5 yrs	Moderate impact
0-5 yrs	No impact
0-5 yrs	Major impact

	What problems do you experience while using this building modeler?
1	Current parametric models can be difficult to use for major process facilties as they were created for vertical cons
2	
3	
4	
5	
6	Some program limmitations
7	Need to further develop my own object library
8	We are limited in expressing are creativity and are not willing to take the time to create a complex 3d model.
9	
10	
11	
12	Takes a fast computer to run it.
13	Just growing pains of trying to make the software work for us. Trying to implement standards for revisions.
14	it was a whole lot slower in terms of machine responsiveness (needed much more capable hardware).
15	hard to transfer electronic data files in its native format.
16	
17	3D modeling packages - in general wont allow the preparation of complete construction-workshop drawings
18	Sometimes parametric is not good - example I now tell things NOT to move
19	
20	
21	creating parametric assemblies can be a tedious process
22	
23	
24	
25	
26	Making the software work like the building process or being constarined by the abilities of the software
27	
28	way too complicated and involved for design of unique (non repetitive components)residential projects. Uniquene
29	the working drawings have to be very percise
30	
31	Its not as easy to fudge things
32	
33	ability to view doors / windows above / below the cut plane as it is viewed at the actual cut level
34	Getting too involved in imaging
35	learning curve
36	Not effeicient for irrugluar structures
37	None at all
38	
39	
40	
41	
42	
43	
44	
45	

Design firms using Revit (obtainrd from Revit's on-line users group)

Barnes Architects

BRM Jerry CAD Design

Dean Robert Camlin & Associates

Degnan Design Builders, Inc.

Department of Transportation CA

DiSunno Architecture

Fitzroy Robinson International

GULIAN DESIGN ARCHITECTS

J. Randolph Parry Architects

Rowe Architects, Australia

Target Architect

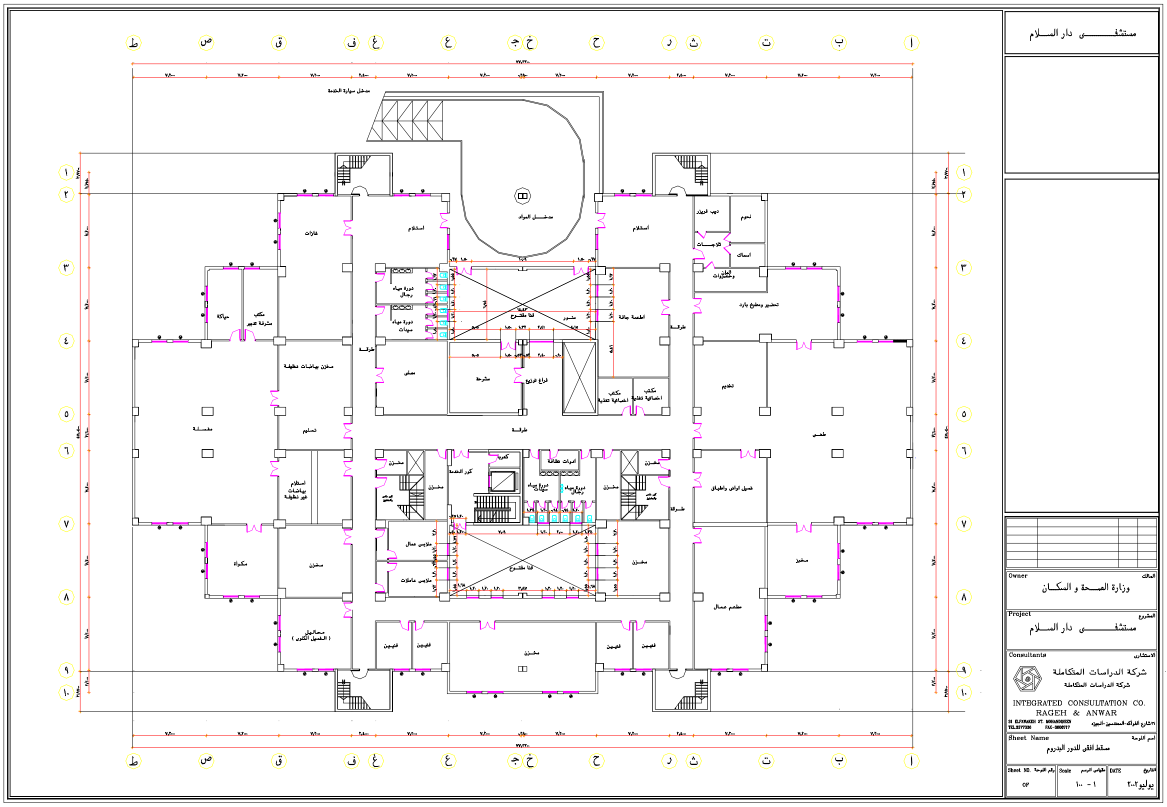
Vaught Frye Architects

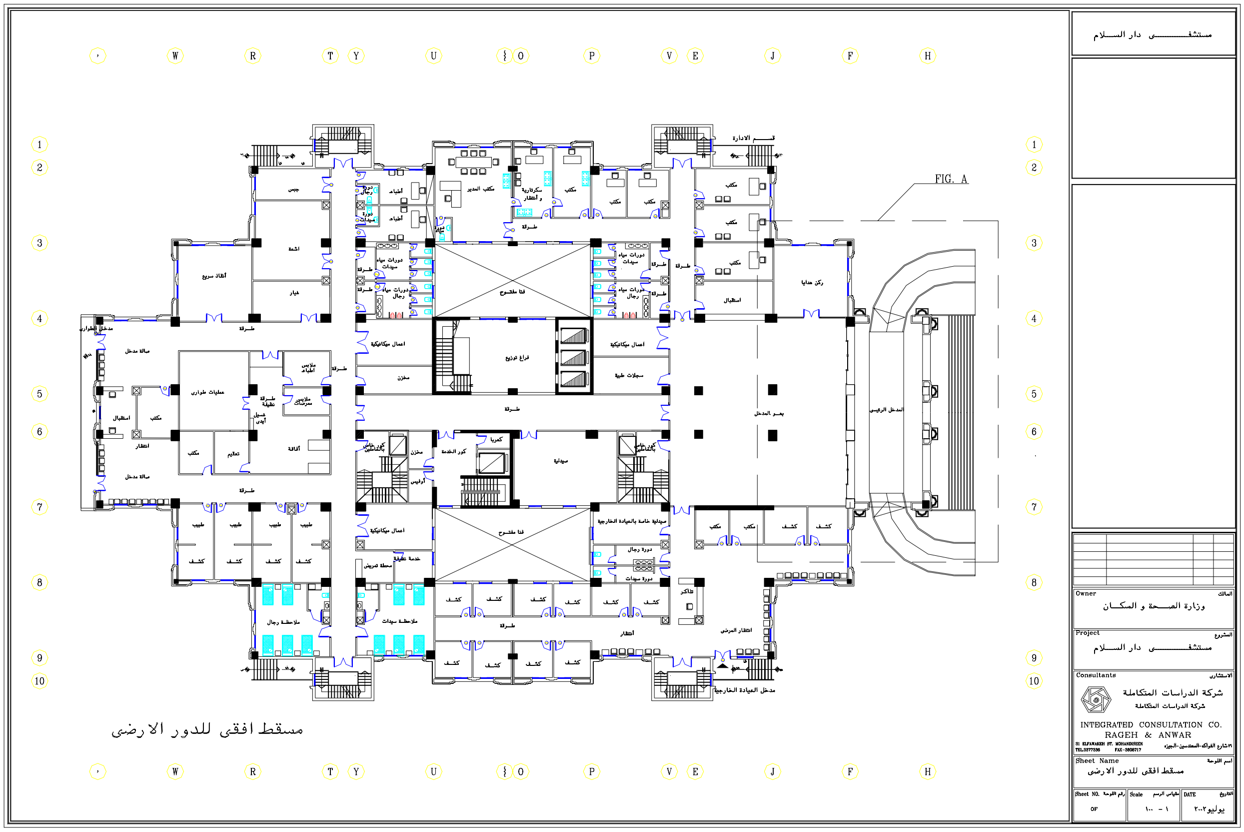
Wimberly Allison Tong & Goo

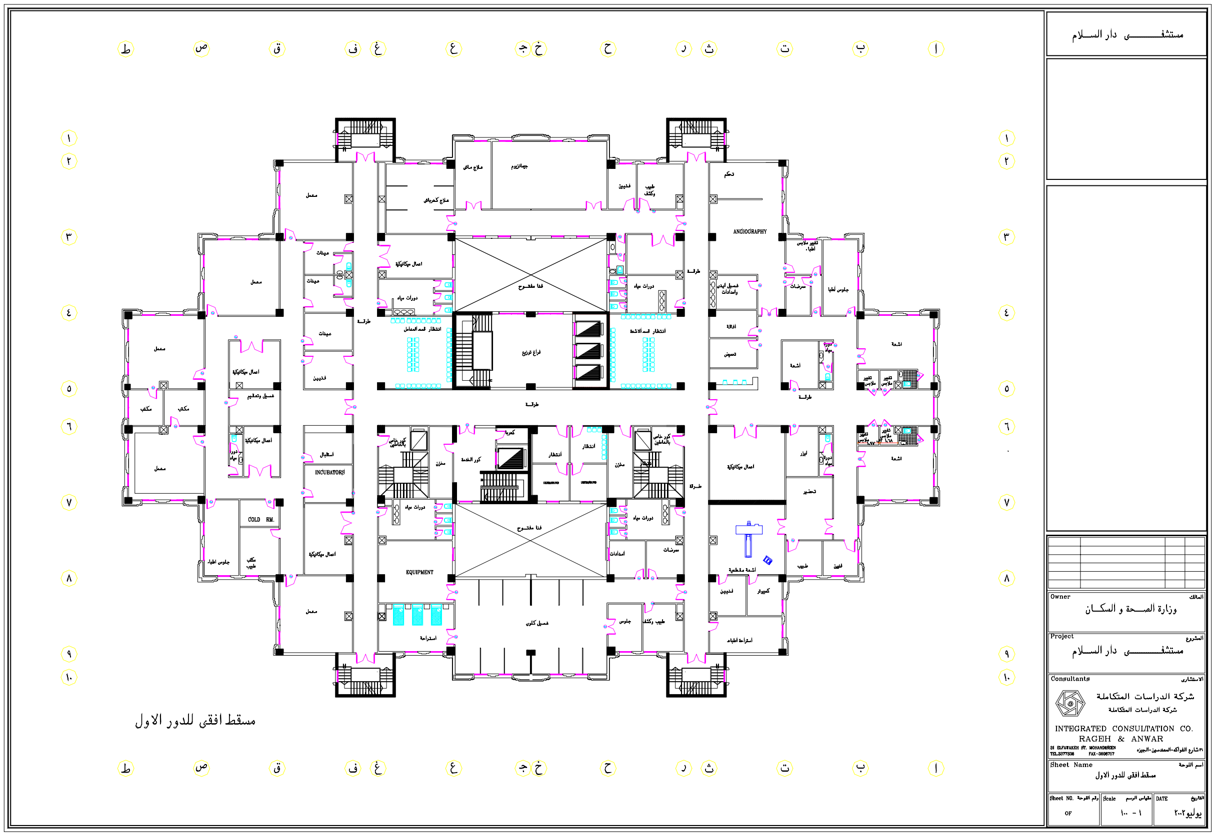
WJ ADAMS Building Designer

WM Design Partnership (UK)

Appendix D Case Study original Autocad drawings




مستشفى دار السلام
FIG. A
قسم الادارة
مسقط افقى للدور الارضى
Owner
المالك
وزارة الصحة و السكان
Project
المشروع
مستشفى دار السلام
Consultants
الاستشارى
شركة الدراسات المتكاملة
INTEGRATED CONSULTATION CO.
RAGEH & ANWAR
31 ELFAWAKEH ST. MOHANDISEEN
TEL.3377336 FAX-3606717
٣١ شارع الفواكه-المهندسين-الجيزه
Sheet Name
اسم اللوحة
مسقط افقى للدور الارضى
Sheet NO. رقم اللوحة
OF
Scale مقياس الرسم
١ - ١٠٠
DATE التاريخ
يوليو٢٠٠٢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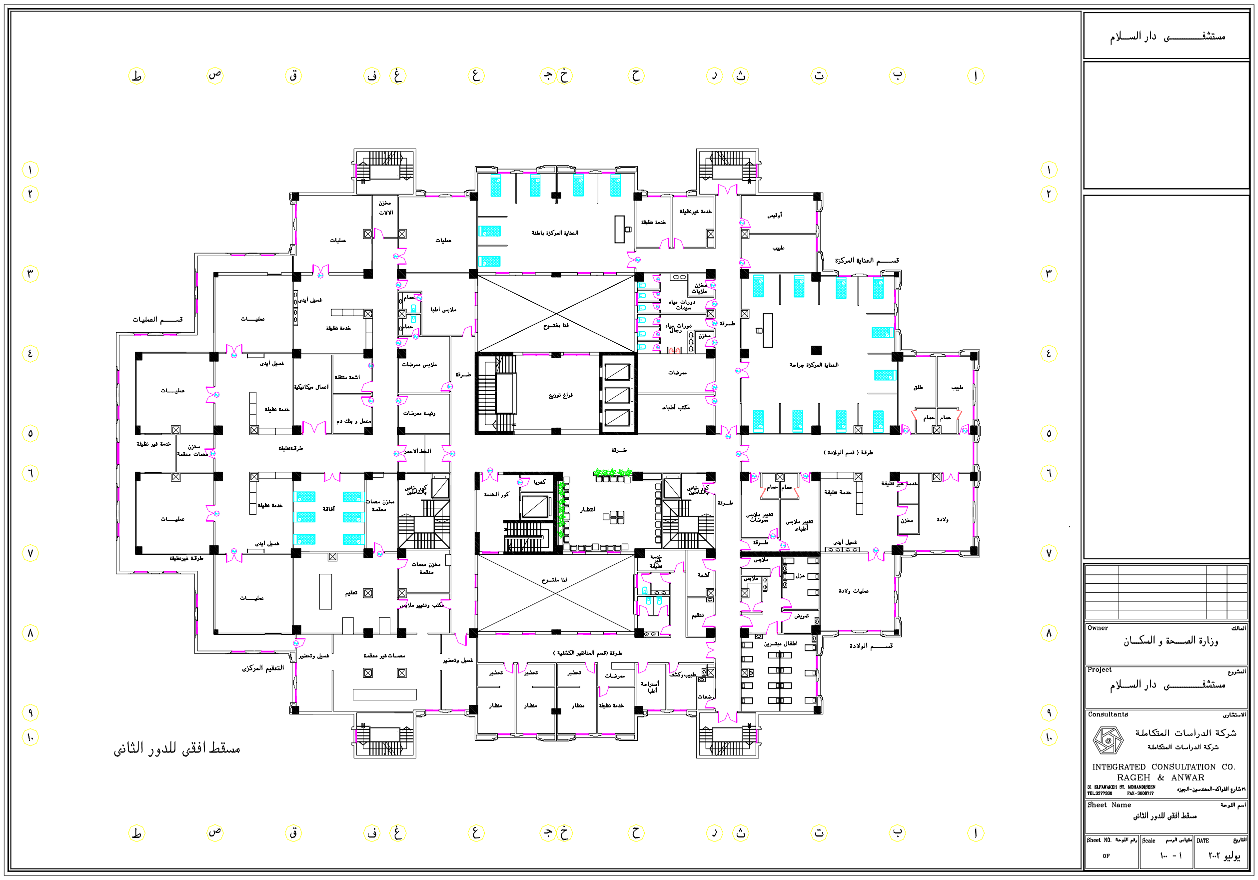
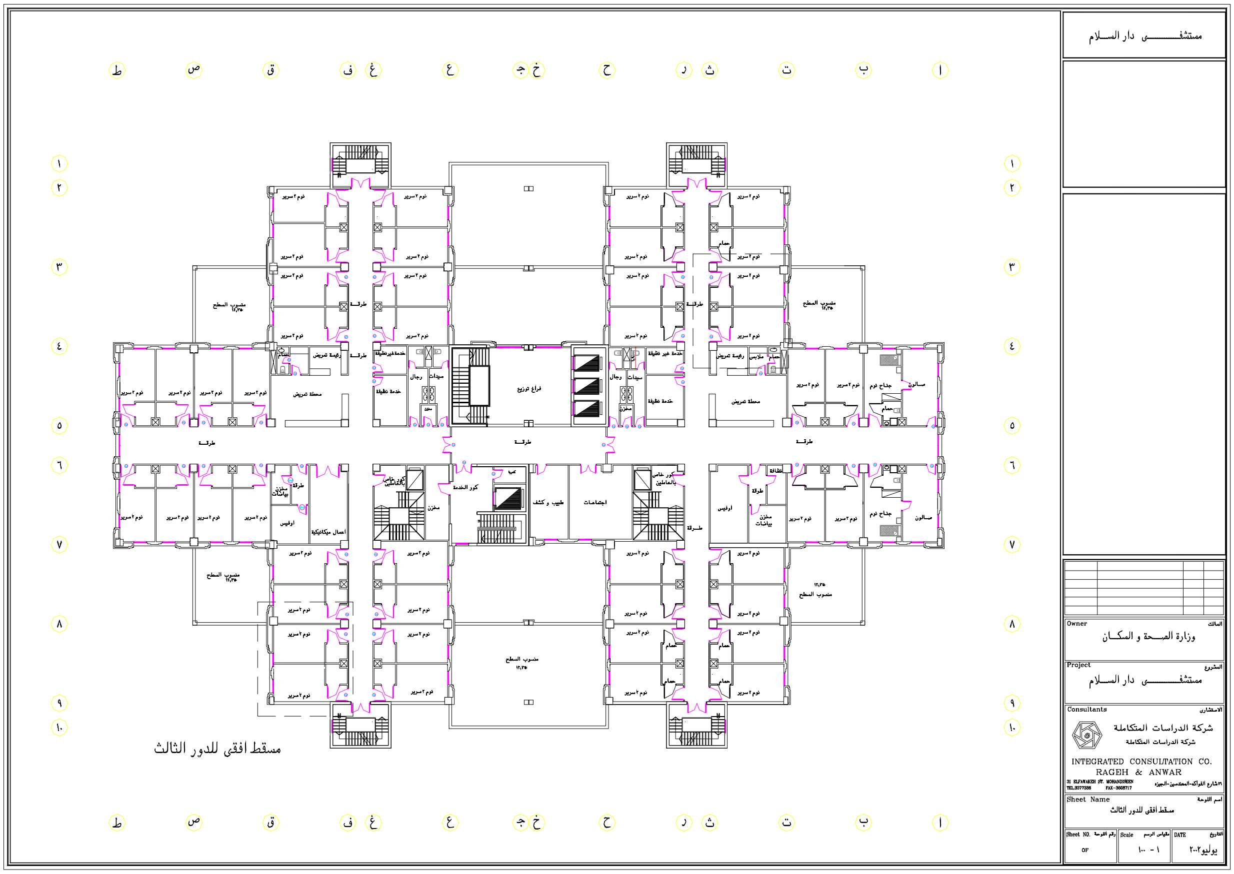
مسقط افقي للدور الاول
ANGIOGRAPHY
INCUBATORS
EQUIPMENT
COLD RM.
Owner
وزارة الصحـة و السكـان
Project
مستشفـــــى دار الســلام
Consultants
شركة الدراسات المتكاملة
INTEGRATED CONSULTATION CO.
RAGEH & ANWAR
Sheet Name
مسقط افقي للدور الاول
Sheet NO.
Scale
DATE


مسقط افقي للدور الثاني
قسم العمليات
قسم العناية المركزة
قسم الولادة
التعقيم المركزي
مستشفى دار السلام
Owner
المالك
وزارة الصحة و السكان
Project
المشروع
مستشفى دار السلام
Consultants
الاستشاري
شركة الدراسات المتكاملة
INTEGRATED CONSULTATION CO.
RAGEH & ANWAR
31 ELFAWAKEH ST. MOHANDSEEN
TEL.3377336 FAX-3608717
٣١ شارع الفواكه-المهندسين-الجيزه
Sheet Name
اسم اللوحة
مسقط أفقي للدور الثاني
Sheet NO.
رقم اللوحة
Scale
مقياس الرسم
١ - ١٠٠
DATE
التاريخ
يوليو ٢٠٠٢


مستشفـــــــى دار الســلام
مسقط افقي للدور الثالث
Owner
وزارة الصـحة و السكـــان
Project
مستشفـــــــى دار الســلام
Consultants
شركة الدراسات المتكاملة
INTEGRATED CONSULTATION CO.
RAGEH & ANWAR
Sheet Name
مسقط افقي للدور الثالث
Sheet NO.
Scale
DATE
يوليو٢٠٠٢