# A FRAMEWORK FOR THE PROCESS OF EFFECTIVE COORDINATION OF BUILDING SERVICES DURING THE DESIGN DEVELOPMENT AND REVIEW STAGES


BY

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*Dedication*

To my parents and sisters

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| **MEP** | : | Mechanical Electrical and Plumbing |
| **BMS** | : | Building Management Systems |
| **NZCIC** | : | New Zealand Construction Industry Council |
| **RIBA** | : | Royal Institute of British Architects |
| **O/M** | : | Operation and Maintenance |
| **A/E** | : | Architecture and Engineering |
| **DEMA** | : | Data Exchange Matrix Analysis |
| **GC** | : | General Contractor |
| **SCOP** | : | Sequential Comparison Overlay Process |
| **HVAC** | : | Heating, Ventilating and Air Conditioning |
| **CC** | : | Cloud Computing |
| **BIM** | : | Building Information Modelling |
| **IDEF0** | : | Integration Definition for Functioning Modelling |
| **U.S** | : | United States |
| **CAD** | : | Computer Aided Design |
| **3D** | : | Three-Dimensional |

# ABSTRACT

Full Name : Babatunde Olusegun Adewale

Thesis Title : A framework for the process of effective coordination of Building services during the design development and review stages

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Major building services are designed independently, leading to conflicts and rework. The study revealed that building services coordination during the building design development and review stage in Saudi Arabia is ineffective. The study also confirms there is a need to develop standardized processes that can be adopted for design coordination. The thesis has three objectives. The first objective is to identify and assess the factors that influence the process of effective coordination of building services during the design development and review stages. Thirty-six factors grouped under six categories were evaluated through a questionnaire survey. These categories include the planning phase of the project, design of MEP systems, construction of MEP systems, operation and maintenance of MEP systems, owner and design team and tools used. Responses were obtained from 30 architects, 30 contractors and 30 facility managers, practicing at the Eastern province of Saudi Arabia. Three tests of agreements were conducted to determine the level of agreement among all the respondents on the importance of the identified factors. The second objective is to develop a framework for the process of effective coordination of building services during the design development and review stages. The framework consisted of five processes, namely “develop the project conceptual design”, “develop the preliminary design”, “prepare the developed design of MEP services”, “prepare the detailed design of MEP services” and “prepare the construction documents of MEP services”. The third objective is to validate the developed framework through conducting interview with ten A/E consulting offices. The average evaluation of the framework phases was “very important” by the professionals who evaluated the developed framework.

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# ملخص الرسالة

**الاسم الكامل:** باباتوندي اولوسيجون أديوالي

**عنوان الرسالة: إطار لعملية التنسيق الفعال للخدمات التشييد خلال مراحل تصميم وتطوير ومراجعة**

**التخصص: الهندسة المعمارية**

**تاريخ الدرجة العلمية:** مايو 2016

صممت خدمات البناء الرئيسية بشكل مستقل، مما يؤدي إلى الخلاف وإعادة العمل. وكشفت الدراسة أن تنسيق خدمات المبنى خلال تطوير تصميم البناء ومرحلة المراجعة في المملكة العربية السعودية غير فعالة. تؤكد الدراسة أيضا أن هناك حاجة إلى تطوير العمليات الاساسية التي يمكن اعتمادها لتنسيق التصميم. هذة الرسالة لها ثلاثة أهداف. الهدف الأول هو تحديد وتقييم العوامل التي تؤثر على عملية التنسيق الفعال للخدمات المبنى خلال مراحل التصميم والمراجعة .تم تقييم ستة وثلاثون عامل تم تجميعهم في ست فئات من خلال الاستبيان. وتشمل هذه الفئات في مرحلة التخطيط للمشروع، وتصميم النظم الكهربائية والميكانيكية و المرافق الصحية ، وبناء النظمة الكهربائية والميكانيكية والمرافق الصحية ، وتشغيل وصيانة الانظمة الكهربائية والميكانيكية والمرافق الصحية ، وفريق المالك للتصميم والأدوات المستخدمة. وقد تم الحصول على ردود من ثلاثون مهندس معمارى و ثلاثون مقاول و ثلاثون من مديرين المرافق العاملين في المنطقة الشرقية من المملكة العربية السعودية. أجريت ثلاث تجارب من الاتفاقيات لتحديد مستوى التوافق بين جميع المشاركين على أهمية العوامل المحددة. والهدف الثاني هو وضع إطار لعملية التنسيق الفعال للخدمات المبنى خلال مراحل تصميم والمراجعة . الإطار يتكون من خمس عمليات، وهما "تطوير التصميم النظري مشروع"، "تطوير التصميم الأولي"، "إعداد التصميم المتطور للخدمات الكهربائية والميكانيكية والمرافق الصحية "، "إعداد التصاميم التفصيلية للخدمات الكهربائية والميكانيكية والمرافق الصحية " و "إعداد ملفات البناء للخدمات الكهربائية والميكانيكية والمرافق الصحية ". والهدف الثالث هو للتحقق من صحة الطار المطور من خلال إجراء مقابلة مع عشر مكاتب الهندسة المعمارية الاستشارية . وكان متوسط تقييم مراحل الإطار "مهمة جدا" من قبل المهنيين الذين قيموا الإطار المطور.

درجة الماجستير في العلوم

جامعة الملك فهد للبترول والمعادن

الظهران، المملكة العربية السعودية

مايو، 2016

# CHAPTER 1
# INTRODUCTION

The twenty-first-century buildings are becoming increasingly complex and the complexities continue to increase year after year more than ever before in the history of man. A building can now be built to a height more than eight hundred meters with floors exceeding one hundred and fifty, to accommodate hotels, offices, commercial malls and recreational areas. New technologies in buildings now have the capability to collect water, solar and wind from the external skin and convert to energy that can be used by occupants. The changes is increasing the architectural design and building services complexities, hence the complexities present challenging coordination problems (Tzortzopoulos and Cooper 2007).

## 1.1 BACKGROUND

To efficiently and effectively manage the building services complexity, the architecture, engineering and construction (AEC) industry is seeking the adoption of new management strategies and more collaboration between professionals at every stage of the project. El-Reifi and Emmitt (2013) explained that the focus must be on the design phase of the building project to reduce uncertainty and improve quality because the construction phase challenges can be solved adequately during the design stage (El-Reifi and Emmitt 2013).

Riley (2000) explained that architectural and structural systems of buildings are usually designed independently of the mechanical, electrical, and plumbing (MEP) systems. MEP systems are subsequently installed into provided spaces and zones with the wrong configuration that will be difficult to construct, access and maintain (Riley 2000). Some past research works had revealed that a high percentage of defects during the production stage originate from decisions during the building design stages (Akbiyikli and Eaton 2012). Effective design coordination can reduce uncertainty at the production stage of the building projects hence field conflict that can affect the delivery time of the project can be avoided (Riley and Horman 2001). Coordination activities are quite challenging due to modern project delivery method, therefore, to complete projects within the time frame is an indicator of efficiency (Riley 2000).

Wan and Kumaraswamy (2012) define coordination as 'the process of managing interdependencies between activities'. Building service is the electrical, mechanical, plumbing systems of the building and designing these systems require the involvement of multiple specialists working independently and inter-dependently. Normally coordination will be conducted during the design stage to avoid systems collusion for the success of the entire Project (Wan and Kumaraswamy 2012).

The construction industry is deeply fragmented and this can be attributed to the traditional differentiation and specialization of the professionals involved throughout the design process. Effective design coordination will drastically reduce project time and cost but currently, a great disparity exists in the design coordination process (Riley and Horman 2001).

The New Zealand construction industry council (NZCIC) separated the building design process into five distinct phases namely; concept design phase, preliminary design phase, developed design phase, detailed design phase, and construction design phase. The Royal Institute of British Architects (RIBA) developed four distinct phases for the building design process namely; preparation and brief phase, concept design phase, design development phase, technical design phase. The successful exchange of information from one phase to the other and exchange of information between designers and building services systems specialties will determine to a great extent the success of the building projects during construction and post construction.

The design phase of construction projects requires information exchange from various disciplines from the brief to the detailed design phase. The design phase process is mostly considered iterative and evolutionary, involving information flows across multiple teams. The multidisciplinary nature of building services makes the coordination process involve various experts, with a different view of the project. Also, the different priorities contribute to the challenging nature of the building service coordination process (Sawhney and Maheswari 2013).

Design coordination is about finding solutions to design errors and conflicts between different building elements that have interwoven dependencies. Design coordination is challenging because when one section of the building is altered, it affects the other parts of the building often creating new problems (Lee 2014). Structuring and planning the design process is difficult and building professionals encounter tremendous challenges in managing the process, most especially large and complex building projects.

## 1.2 STATEMENT OF PROBLEM

Several types of research had indicated that errors and problems originating from the design stage will increase project budget and cause project delay. A study conducted by El-Reifi and Emmitt (2013) in all the project stages to determine which stage is most responsible for rework that causes conflicts, delay and increased budget leading to low-value project delivery to clients. The design development stage was concluded to be the most responsible for rework. Other stages were also highlighted as responsible for construction conflicts, caused by inefficiency and nature of the design process (El-Reifi and Emmitt 2013).

Mostly, building services (MEP systems) are fit into spaces that are predetermined and such spaces are of low priority. MEP systems are allocated limited spaces because they are viewed as expensive unusable spaces that should be used for building functional spaces. Cramping of piping, ductwork, and electrical systems into tight spaces lead to an inefficient configuration that is difficult to detail, construct and maintain (Riley 2000). Attributes causing this inefficiency and delay sometimes are design changes, poor communication, poor coordination and inadequate planning (Assaf and Al-Hejji 2006).

Errors, design changes, and poor coordination at the design stage will cause systems installation interference which will result in demolition, replacement, rework and material waste. Wan and Kumaraswamy (2012) explained that building services contractors inherit design from architects and consultants and any correction and error will precipitate repetitive works. In essence, building services require effective coordination for effective delivery of building projects (Wan and Kumaraswamy 2012).

The quality of coordination has been directly linked to lower project cost, reduced project time, enhanced project quality, increased productivity, improved safety performance, minimized contract change order and disputes (Yung et al. 2014).When conflicts are discovered on a construction site, it is often late to prevent some form of interruption and this cause delay (Riley 2000).

Riley (2000) states that the average cost of fixing a field conflict on an average project was found to range from $500-$3500 for minor rerouting, $2,000-$25,000 for major conflict and design change. Another key factor that adds to the overall cost of a project is the occasional interruption of the work crew, though measuring this has been challenging.

The total cost of the building services of a building project can cost more than half of the total contract sum, which makes it very important to the overall financial success of the building. Although some of the systems are similar in nature, separate professionals still design them. Building services coordination has been historically challenging. The importance of managing the design stage effectively and efficiently has been made clear however much of the research and effort has been expended on the construction phases (El-Reifi and Emmitt 2013).

This thesis will offer a new approach to building services coordination during building design. The new approach will reduce errors, rework, demolition and construction waste during the preconstruction and construction stage of building projects.

## 1.3 RESEARCH OBJECTIVES

The main objectives of the research are:

1. To identify and assess the factors that affect the process of effective coordination of building services during the design development and review stages from the perspective of design professionals, contractors, and facility managers.

2. To develop a framework for the process of effective coordination of building services during the design development and review stages.

3. To validate the developed framework through conducting interviews with ten consulting offices in Eastern province of Saudi Arabia.

## 1.4 SCOPE AND LIMITATIONS

The followings are the scope and limitations of this research;

1. The development of the framework for the process of effective coordination of building services during the design development and review stages shall be limited to the knowledge obtained from the literature and observed professional practice.

2. The distribution of the questionnaire survey and interview shall be limited to professionals working with registered A/E offices, contractors, facility and building managers in Eastern province of Saudi Arabia.

## 1.5 SIGNIFICANCE OF THE STUDY

Building services constitute a complex subsector of the construction industry. Coordinating architectural, structural and MEP elements during the building design phase can be challenging. The building services coordination must be properly managed to prevent errors during the construction and the operational phase of the building project. Errors in the process will cause building services installation interference, leading to clashes and conflicts during construction. Errors will lead to demolition, replacement and rework causing material waste. The consequences of poor coordination at the design phase will also affect the operational and maintenance phase of the building project. Hence, the importance of the study emanate from;

1. The study has the possibility to improve the process of building services delivery which leads to increased efficiency in the construction industry.
2. The study will be beneficial to design professional because building services coordination process can be more effective and efficient.
3. The study will reduce errors that cause non-value adding activities during the preconstruction and construction phase.
4. Current coordination practices during the design development phase would be improved upon to meet the increasing construction industry in Saudi Arabia.

5. The findings of the study would be directly relevant and applicable to building projects in Saudi Arabia.

## 1.6 RESEARCH METHODOLOGY

The research plan to achieve the objectives of the thesis consists of six main phases (see figure 1);

### 1.6.1 Phase 1 – Investigation of Building services coordination process

This phase will investigate the international and local building services coordination processes, through;

#### 1.6.1.1 Identification of the International building services coordination practices.

This step will be carried out through a detailed literature review to understand thoroughly the field of building services coordination, and also to identify the international frameworks in which the existing processes are reported.

#### 1.6.1.2 Identification of the Local building coordination practices.

This step will be carried out through conducting interviews with selected sample of ten Architectural and Engineering offices in Eastern province of Saudi Arabia for understanding the local building services coordination practice (see Appendix 1).

### 1.6.2 Phase 2 – Identification and assessments of the factors influencing the process

Identification of various factors influencing building services systems coordination will be through literature review and interviews with design professionals. Subsequently, the factors will be assessed by design professionals, contractors, and facility/building managers. This phase entails:

#### 1.6.2.1 Development of questionnaire survey

Developed questionnaire survey will be administered to a group of design professionals, contractors, facility managers in the Eastern province of Saudi Arabia. The questionnaire will consist of two sections:

a. Section 1: Respondent's area of professional expertise and experience.

b. Section 2: identified factor assessments.

The professionals will be asked to mark their observed level of importance for each of the identified factors through selecting one of five evaluation terms, namely 'Extremely Important' with 4 points, ' Very Important' with 3 points, 'Important' with 2 points, 'Slightly important' with one points and 'Not important' with zero points.

#### 1.6.2.2 Sample size

The identification of the type and size of professionals will be determined during this stage;

**1. A/E offices sample size:**

- The professional's respondents will be determined from the list of A/E offices collected from chamber of commerce and industry Eastern province.
- Equation 1.1 and 1.2 will be used to determine respondents size (kish 1995):
  - $n_{\circ} = (p*q)/v^2$……………..… (1.1)
  - $n = n_{\circ}/ [1+ (n_{\circ}/N)]$………… (1.2)

Where:

$n_{\circ}$: First estimate of sample size

p: The proportion of the characteristic being measured in the target population.

q: Completion of p or 1-p.

v: The maximum percentage of standard error allowed (10% for this study)

N: The population size.

n: The sample size.

Note: To maximize the sample, both p and q are each set at 0.5.

2. **Contractors' offices sample size:**

- The professionals respondents will be determined from the list of construction offices collected from chamber of commerce and industry Eastern province
- Equation 1.1 and 1.2 will be used to determine respondents size (kish 1995):

3. **Facility/building managers' offices sample size:**

- The professionals respondents will be determined from the list of facility management (O/M) offices collected from chamber of commerce and industry Eastern province
- Equation 1.1 and 1.2 will be used to determine respondents size (kish 1995):

#### 1.6.2.3 Questionnaire survey pilot testing.

Pilot testing of the developed questionnaire will be conducted among the identified design professionals, contractors and facility managers based in Eastern province of Saudi Arabia to achieve the following:

- Adequacy of the questions.
- Identify ambiguities.

- Adding more factors.
- Checking spaces provided for questions.
- The determining of time required for answering the survey.

**1.6.2.4 Distribution of the tested questionnaire survey**

At this step, the pilot-tested questionnaire survey will be distributed to the various survey participants in the Eastern Province of Saudi Arabia to assess the identified factors.

## 1.6.3 Phase 3 - Data Analysis

The analysis of the received data from the A/E offices, contractors, facility managers to the questionnaire survey will be analyzed with the steps below;

**1.6.3.1 Calculation of the important index**

Using Excel program, an importance index will be calculated to reflect the level of importance of those factors. This index will be calculated using the following equation 1.3 (Dominowski 1980):

$$Importance\ Index\ (I) = \frac{\sum_{i=0}^{4}(ai)(xi)}{4\sum_{i=1}^{4}(xi)} * 100\% \qquad \ldots\ldots\ldots\ldots\ldots(1.3)$$

Where:

i = Response category index where i= 0,1, 2, 3, 4

ai = Weight given to i response where i= 0, 1, 2, 3, 4

xi = variable expressing the frequency of i as illustrated in the following:

$x_0$= frequency of "Extremely Important" response corresponding to $a_0$= 4.

$x_1$ = frequency of "Very Important" response corresponding to $a_1$ = 3.

$x_2$ = frequency of "Important" response corresponding to $a_2$ = 2.

$x_3$= frequency of "Somewhat Important" response corresponding to $a_3$ = 1.

$x_4$ = frequency of "Not Important" response corresponding to $a_4$ = 0.

The importance index of 0–<12.5% is categorized as ‘‘Not Important’’; 12.5–<37.5% is categorized as ‘‘Somewhat Important’’; 37.5–<62.5% is categorized as ‘‘Important’’; 62.5–<87.5% is categorized as ‘‘Very Important’’; and 87.5–100% is categorized as ‘‘Extremely Important.’’ The categorizations reflect the scale of the respondents' answers to the questionnaire.

The test of agreements between the Architects, Contractors and Facility Managers will be calculated using "The Rank-Order Coefficient of Correlation" formula 1.4 (Assaf et al. 2015);

$$p = 1 - \frac{6 \sum D^2}{N(N^2-1)} \quad \text{.......................... (1.4)}$$

Where;

$p$ = Is the rank order coefficient of correlation.

$\sum D^2$= Is the sum of the squared differences in ranks of the paired values.

N = Is the number of parameters for which the ranking in made.

### 1.6.4 Phase 4 – Development of Framework

This phase entails the development of a framework for the effective coordination of building service systems during the design development and review stages. The development of the framework will be based on all the information gathered from the literature review, interviewing practicing professionals and questionnaire survey.

### 1.6.5 Phase 5 – Validation of the developed framework

The developed framework will be validated through interviews with ten A/E companies practicing in Eastern Province of Saudi Arabia. This is to determine how applicable the developed framework is to the Saudi construction industry.

### 1.6.6 Phase 6 – Conclusions and Recommendations

Conclusion and recommendation will be made based on the final results and future research areas will be specified.

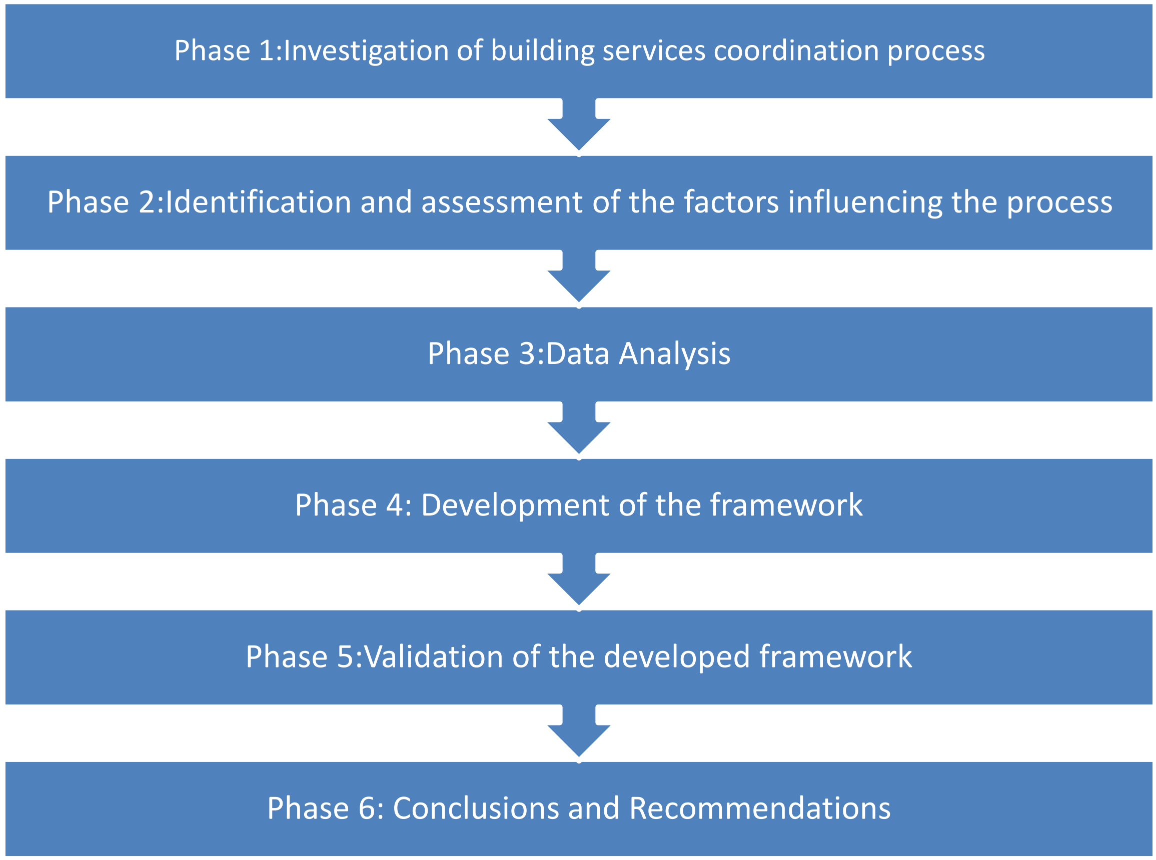


Figure 1 - Research Methodology flow chat.

## 1.7 THESIS ORGANIZATION

The organization of the thesis sub-divided into the following seven chapters for the attainments of the research objectives;

**Chapter one: Introduction**

Presentation of the general background information on buildings services and coordination. The problem statement, objectives, scope and limitations, significance of the study, research methodology and thesis organization.

**Chapter two: Literature Review**

The literature on building services and coordination, definitions, features, challenges of building services systems coordination, as well as the international practice of coordinating building services at the design development and review stages.

**Chapter three: Current local Practice for Building Services Coordination.**

Explained the local practices of building services coordination in Eastern province.

**Chapter four: Factors Affecting the Effective Coordination of Building Services.**

Presents the factors affecting the effective coordination of building services.

**Chapter five: Assessments of the Factors**

Explained the data analysis and results received from the distributed questionnaire survey among the professionals respondents in Eastern province, Saudi Arabia.

**Chapter six: Development of the Building Services Coordination Framework**

Presentation of the development of the framework for the process of effective coordination of building services during the design development and review stages of building projects.

**Chapter Seven: Validation of the Developed Framework**

Explains the process of validating the developed framework by professionals practicing in Eastern province of Saudi Arabia.

**Chapter Eight: Conclusions and Recommendations**

The conclusions, summary of the study, recommendations, and future research areas was presented under this chapter.

# CHAPTER 2
# LITERATURE REVIEW

The literature review will entails obtaining detailed information about building design processes. The literature review will include past framework proposed for the effective management of building services coordination. In-depth investigation of building services coordination strategies that will improve the process will be conducted. Three main topics are explained in this chapter namely buildings, coordination of building services systems and previous studies on the research.

## 2.1 BUILDINGS

### 2.1.1 Building Design Processes

Building design processes involve multiple stages and the collaboration of several professionals to ensure the overall success of the building project. Current building design processes are focused on design deliverables (e.g. 30%, 60%, 90%, or 95% complete drawings). At each phase of the building design process, project information's are made available by the participating professionals (Choo et al. 2004). The participating professionals are called the building design team.

The Architect contribution to the design process is most significant at the concept and schematic stage. The Architects responsibility continue to the subsequent stages of the entire design phase. The principal role and concern of the engineering professional members (e.g. Mechanical, Electrical, Plumbing) of the building design team are the building services and structural engineering elements of the building projects (Gray and Hughes 2001).

The building design team activities are interrelated, and adopting a suitable sequence of work will reduce error and wasteful rework. The building design process is often difficult but very important for the overall project success (Choo et al. 2004). The design process is difficult because research has proven that decisions made by the design team affect the building from the pre-construction phase to the operational and maintenance phase. New Zealand Construction Industry Council (NZCIC), Royal Institute of British Architect (RIBA), American Institute of Architects (AIA) have all developed different types of work stages and activities involved in the building design process. The primary work required during the building design phase is contained in the plan of work irrespective of the Professional body.

Due to increasing complexities of building design process and because effective building design management is important, there is an increased focus on design process coordination and how it can be used to reduce the cost of buildings, increasing efficiency and overall delivery of the building project (Choo et al. 2004). The design process should ensure that all aspect of the building services is effectively coordinated and detailed. Buildings are mainly composed of three main systems namely, architectural, structural, and MEP systems which can be regarded as the skin ,skeletal ,and cardiovascular systems of a human body respectively (Lee 2014).

### 2.1.2 Building Services

Building services termed as the active building systems include mechanical, electrical, and plumbing (MEP) systems. Building services must meet the expected performance regarding comfort and safety, it must fit within the constraints of architecture and structure (Korman et al. 2003). Building systems moderate the building environments, distribute electric energy, allow communication, enable critical manufacturing process, provide water and dispose of waste, and provide critical resources for life safety (Korman et al. 2008).

The scope of building services systems is continually increasing due to increasing requirements for building users. Building projects now include more than the traditional Mechanical, Electrical, and Plumbing systems, such inclusion is fire protections, controls, process piping, and telephone/datacom (Korman et al. 2008).The active systems of the building namely mechanical, electrical, plumbing, and fire protection (MEP/FP) systems has been estimated to cost up to 60% of the total cost of the building projects (Korman and Huey-King 2013).

Although MEP systems are fit into zones, plenums and shafts provided by the architectural and structural systems, these provided spaces are mostly limited in sizes. The spaces are limited because of the cost implication of unusable spaces. The limited spaces cause MEP system cramming into tight spaces difficult to detail, construct and maintained (Riley 2000). Therefore, building services systems requirements must be considered from the beginning of the building design phase. Furthermore, the coordination of cross-disciplinary information among all design disciplines involve at the design phase, must be done with the knowledge of the implication of the decision made towards the building construction projects.

## 2.2 COORDINATION OF BUILDINGS SERVICES SYSTEMS

### 2.2.1 Definition of Building Services Coordination

Korman and Huey-King (2013) defined building services coordination as the arrangement of the building services components to fit into the constraints of the building architecture and structure. Wan and Kumaraswamy (2012) defined coordination as the process of managing interdependencies between activities. Building services coordination is essential for the determination of location and characteristics of the HVAC, electrical, process, plumbing, fire protection, and other systems (Korman and Tatum 2000) . Design coordination of MEP systems can be extremely difficult to conduct on complex and mechanically intensive building projects and the level of effectiveness will affect immensely field conflicts of the building services systems during the construction stage (Riley et al. 2005).

Building service coordination is an exercise conducted during the design phase to focus on required integration and design decisions. Furthermore, the coordination activity must be conducted during the design phase to ensure design team interactivities and improvement of the quality of the building design. Achieving effective building services coordination will reduce the challenges encountered during the pre-construction, construction and operational stages of the building (Liu and Melhado 2010). Tabesh and

Staub-French (2005) define MEP coordination as ‘the arrangement of components of various building systems within the constraints of architecture and structure’

Building design coordination is an iterative activity embarked on to locate building design errors and conflicts, within various building elements such as walls, doors, beams, columns, pipes, ducts, and lighting fixtures that are connected interdependently. This phenomenon makes the building design coordination challenging and difficult. As building design matures, so also is the building services systems to coordinates increases exponentially (Lee 2014).

Korman and Tatum (2006) explained building services coordination as a broad spectrum of several coordination activities during the life of a construction project. Common among the range of coordination activity are MEP systems integration into the architectural and structural envelope, MEP detailed trade drawings integration.

The coordination of building services can also be defined as the arrangement of various building system components which are critical to the functionality of the building. Building services coordination involve the defining of the exact location of the building services components throughout the building while adhering to design and operational criteria (Korman et al. 2010). Building service coordination involves assigning horizontal and vertical location for individual systems component within the defined architectural and structural constraint. Mostly the professionals conducting the coordination process focus on highly congested spaces within the structural systems to prevent systems interference.

Depending on building complexity, building services professionals must ensure that systems meet the intended performance expectations. Comfort, safety, energy efficiency, operations and maintenance criteria are such important expectations. The difficulty encountered in the building services coordination is proportional to the design complexity of the building systems (Korman and Huey-King 2013). Korman and Huey-King (2013) further explained that the main objective of coordination is to achieve the most economical arrangement that suits design criteria and performance specifications, which allow efficient systems components installations.

### 2.2.2 Elements of Building Services Systems

The coordination of the building services (MEP) with other building system entails various activities during the design phase (Korman et al. 2010). Literature study revealed that building services are a broad range of systems that are directly or indirectly interconnected. Careful coordination of all the building services must be ensured to achieve a seamless relationship during construction and operational phase of the building project. The fundamental building systems classifications are; architectural system (indoor and outdoor separation :wall, fenestration, roofs); structural system (elements providing static equilibrium against gravity and dynamic loads); building services (HVAC, electrical, plumbing, vertical transportation, and life safety systems); interior systems (occupied space encompassing partitions, finishes, lighting, acoustics, and furniture); site service (landscape and support systems for the building, including parking, drainage, vegetation, and utilities) (Bachman 2004).

**Building service [HVAC systems]**

Heating, ventilating and air conditioning system design focuses on the building interior's thermal and atmospheric conditions, generally referred to as HVAC. The HVAC systems are responsible for the complete conditioning of the interior air, which may include the filtering of dust and odors, freshening with outdoor air, adjustment of the air temperature and adjustment of the relative humidity. The system should achieve a healthful and comfortable air conditioning for the building occupants. Local climates, building occupancy attributes, building size, shape, and construction types are the important factors and variables that affect the design and fabrication of the HVAC systems (Ambrose 1992).

The HVAC systems comprise of the following functional components : thermal plant where heating and cooling are generated; distribution channels for the thermal energy allotted to building zones; forced air or radiant temperature delivery for occupants; the control system for HVAC operations and thermal loads balancing; thermal energy storage (TES). The relationship between the HVAC systems and the general building design is affected by space for the HVAC equipment; Spaces for air duct; properties of the building enclosure; building planning and noise/vibration (Bachman 2004).

**Building service [Electrical systems]**

Electrical systems design is an integra part of the building services, virtually all mechanical equipment in the building required electrical power. The design and selection of the electrical systems are greatly influenced by the mechanical systems adopted. Exponential increase in communication and information systems in buildings has made the demand on electrical systems increased. Electrical systems in the context of all other building services require a small percentage of building space. A reasonable number of the electrical operating devices are exposed in the living internal space, making it paramount for the designers to coordinate effectively the location and aesthetics to be well coordinated with the architectural and structural systems.

The electrical systems design is approached basically by the following steps which might be adhered to sequentially or not : analyze building needs; determining electrical loads; select electrical systems; coordinate with other design decisions (Architectural systems, structural systems etc.) and lastly preparation of electrical and specification plans. There are different factors that affect the electrical design systems depending on the need established by the architectural program. The factors include architectural factors; occupation factors; cost factors; building environments; illumination criteria; mechanical systems; building equipment; auxiliary systems and future needs (Janis and Tao 2013).

**Building service [Plumbing systems]**

Plumbing systems are referred to as the piped system network installed for water supply, waste drainage, and natural gas. Each of this system has unique design approach. Pressurization is a critical concern when designing the water and gas supply systems while waste drainage system design is anchored on gravity flow. The plumbing systems are directly connected to the public supply main which has to be factored into the building base and foundation design. Fire sprinklers, fire-fighting, irrigation, internal roof drainage and sometimes pressurized air pipe are also part of the plumbing systems depending on the functionality and occupation of the building. Primarily plumbing systems are subdivided into three categories namely; supply point (mains); the pipe distribution systems and terminal components. All these components must all be considered and accommodated during the building design and coordination process to improve the construction process (Ambrose 1992).

**Building service [Vertical transportation]**

The increasing level of high-rise buildings has precipitated different design of moving people and materials from one level to another level. In basic buildings vertical circulation can be achieved by stairs and ramps, however in more complex buildings powered systems must be provided. Elevators and escalators systems are the most common while commercial and industrial building projects tend to have special design systems for material and equipment movements. Big buildings must accommodate vertical transportation housing space for the traveling carrier (elevator cab, belt loop of the escalator). Also to include housing spaces for operating equipment and overruns spaces at the end of the travel path. Space and location planning combined with noise and vibration are some of the challenges engineers encounter when designing transportation systems (Ambrose 1992).

**Building service [communications, Life safety, and security systems]**

Communication, life safety and security systems are part of the building telecommunication systems relying on electrical systems for functionality. It is sometimes considered as information systems. The information systems of buildings have increased exponentially due to the rapid increase in the complexity of buildings. These particular building services systems comprise of data, communication, security, audio visual, life safety systems, sound, signal, building automation and fire alarm systems.

Buildings now need more state-of-the-art technology to function more effectively and efficiently. The building systems design engineers and architects need to accommodate the building information systems required in today's building. Furthermore, because these systems require the expertise of specialist engineers that traditionally are not involved in building systems coordination activities, their inclusion has increased the scope of the coordination activities (Janis and Tao 2013).

### 2.2.3 Professionals Involved in Coordination

Architectural and structural systems are designed first on building projects, followed by the schematic designs of MEP systems (Riley 2000). Architect / Engineers typically develop the schematic design of MEP systems layout and routing. Ashuri et al (2014) explained that MEP coordination is a task that is conducted as a part of architectural, structural and engineering design process of construction projects.

The efficiency and effectiveness of services system are the primary concern of the specialist that designed each system and also the design architect. A major concern to the architect and structural designer is incorporating the building services systems into the building design. Another concern is the fusion of the individual services systems into the whole fabric of the building, an integrated task which is a primary function of an architect. Individual service designer must ensure that all required information is passed on to the architect for determination of the anticipated requirements of individual systems (Ambrose 1992).

Building services coordination process is performed by these professionals to ensure that materials and equipment's intended for any given space in the building is prevented from physical conflicts or impair the installation and maintenance of individual building systems.

### 2.2.4 Building Services Coordination Relevant Knowledge

For building services coordination process to achieve its goals and objectives the coordinators and participants use different knowledge to evaluate and coordinate the configurations of MEP systems. Korman et al (2003) concluded that information from three knowledge domain has great influence on coordination and determine the outcome of the activity. Design criteria and intent knowledge; construction knowledge; operations and maintenance knowledge are the broad domain of knowledge that will assist professionals. The detail of the knowledge overview are (Korman et al. 2003), (Yung et al. 2014);

A. Design criteria and intents / knowledge;

1. *Aesthetic considerations,*
2. *Material considerations,*
3. *Insulation and clearance requirements,*
4. *System function and performance,*

5. *Support requirements.*

B. Construction issues / knowledge;

1. *Fabrication considerations,*
2. *Sequencing considerations,*
3. *Start-up and testing requirements,*
4. *Installation considerations,*
5. *Safety requirements.*
6. *Tolerance and variance,*
7. *Productivity.*

C. Operation and maintenance;

1. *Accessibility requirements,*
2. *Connection considerations*
3. *Safety considerations*
4. *Expandability and retrofit requirements*
5. *Performance*
6. *Space*

### 2.2.5 Building Services Coordination Challenges

Building services coordination is characterized by several problems and challenges. These problems are related to current practices in the building coordination activities among participants such as architects, structural, mechanical, plumbing, electrical engineers in the building design process (Korman and Tatum 2006).

Several types of research have investigated the problem facing building services coordination (Korman and Tatum 2006; Olofsson et al 2007; Korman et al. 2008). Variously identified problems are classified into two categories; category one are the problem encountered with building coordination current practices while categories two are the typical problem encountered by the professionals in relation to individual building services systems.

## 2.3 PREVIOUS STUDIES

The literature review reveals that most of the studies on building services coordination seek to reduce conflicts, design uncertainties and errors. A concept such as dynamic coordination buffering, JAVA tool, sequential cascading process, and building information model process tool, are some of the few ideas proposed to increase efficiency of coordination exercise. The frameworks are explained below;

### 2.3.1 Framework based on the dynamic coordination buffering.

Wan and Kumaraswamy (2012), developed a process to improve building services coordination during the pre-installation stage. They acknowledged that design coordination is important for effectiveness in the building services subsector. 'Dynamic buffering method' used in the manufacturing was adopted because professionals have the tendency to perceive extra time availability as an opportunity to defer activities until the 'last minute'.

A reliability buffer was developed to advance the dynamic buffering by adaptably releasing project buffers that are fixed into individual activities. The buffer was placed (reliability buffer) in front of successive activity as shown in Figure 2. The framework proposed will present a chance for absorbing uncertainties. It will facilitate intra-inter dependent relationships. The study indicates that 'coordination buffers' can be incorporated to check whether designs or uncertainties included in drawing or equipment submissions are resolved totally. This activity reduces nonvalue-adding demolition, replacement, and reworks.

As illustrated in figure 2, the project buffer $\boldsymbol{b_o}$ is traditionally allocated at the end of the activity to guarantee the performance of individual activity subsequent activities. They proposed the 'dynamic coordination buffering' to start with resizing project buffer to $\boldsymbol{b_1}$ and then reallocating and feeding coordination buffers $\boldsymbol{C_a}$ and $\boldsymbol{Cc}$ at the beginning and the end of individual activities. Eventually, the addition of all the buffers ($b_1$, $C_a$, **Cc**) is likely equal to the traditional project buffer $\mathbf{b_0}$. Introducing buffer $\mathbf{C_a}$ in front of initially planned activity will ensure a thorough review and resolve all design or related uncertainties. It will create room to allocate adequate resources, prepare and coordinate with other participants. This will reduce any interference or conflict at the same work area prior to start of activities at time ***to***. They argued that this approach will protect the whole project from being disrupted by failures.

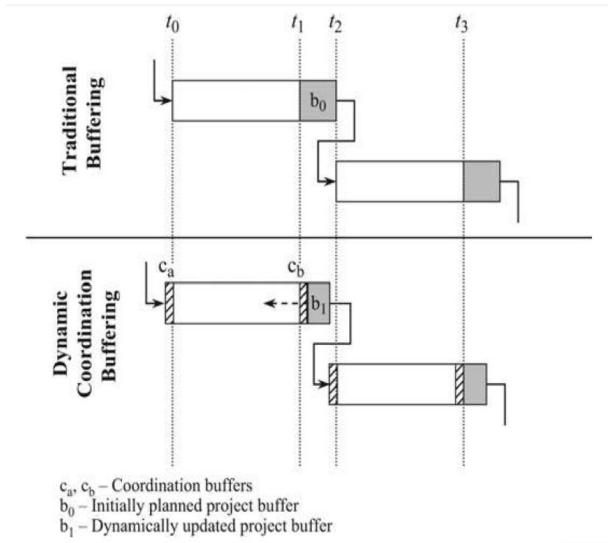


Figure 2 - flow of dynamic coordination buffering (Wan and Kumaraswamy 2012)

### 2.3.2 Framework JAVA tool based on IDEF model for the system.

Korman and Tatum (2006) developed a prototype MEP coordination tool in JAVA for use during the design stage. An object-oriented symbolic modeling language composed of 3D objects. The objective of the tool is to integrate the knowledge bases-design criteria, construction, operations, and maintenance, into an efficient knowledge-based system that provide valuable insight for engineers and construction personnel. Integrating the various knowledge into the systems is to serve the primary purpose of assisting in MEP coordination during the designing. The idea is based on a structure shown in Figure 3, revealing coordination tool's input, mechanisms, control and output. Figure 3 also show how individual models of building systems are fused into one composite model.

**Inputs:** the coordination tools input consist of product model which represent the facility geometric model. Structural and architectural components of the facility that makes up the building envelope and product information are the components in the model. The product information is project specific, includes; component cost, material type, insulation type and size, access space and frequency, installation time, and installation sequence.

**Control:** this is the integrated knowledge base of the coordination tool. Design, construction, operation, and maintenance requirements of each component are the considered knowledge. They eventually serve as a platform for comparison to determining interference.

**Mechanism:** this section performs the necessary data abstraction and data comparison to detect interferences in the geometric model. Subsequently mechanism aid rearrangement of the components after eliminating interferences. The mechanism functions in five different stages (Figure 4);

1. **The expand**: fills in the component attributes [ design clearances, insulation, pipe and duct supports, installation clearances, access and operation space requirements ]
2. **The interferes**: Determines and classify the interference of components in the product model.
3. **The relationships**: Determines the topological characteristics, specifically the spatial relationships and spatial adjacencies.
4. **The evaluate:** information obtained at the interferes and relationship stage is used for coordination.

5. **The rearrange:** Aid the rearrangement of the coordinated product model after conflicts resolution.

**Output:** the output is a coordinated product model of the entire facility. After considering the three major criteria and constraints of MEP coordination [design, construction, and operations and maintenance].

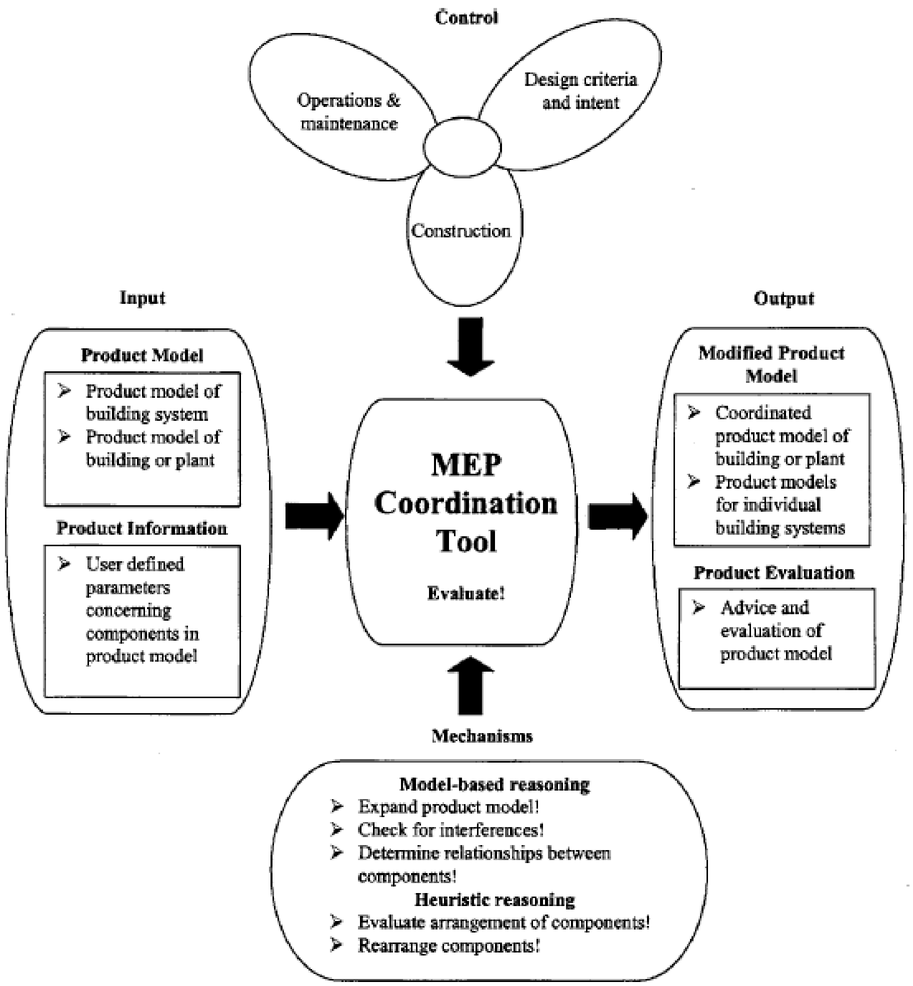


Figure 3 - IDEF (Integration definition function) model for system (Korman and Tatum 2006)

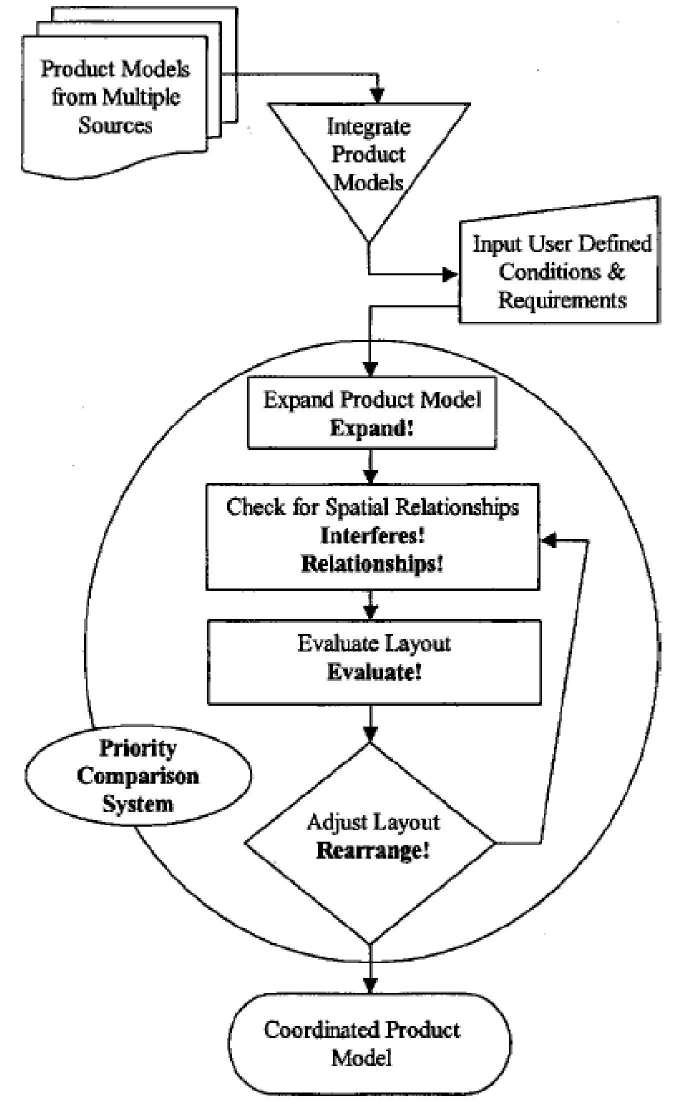


Figure 4 - Flowchart for mechanical, electrical, and plumbing coordination tool (Korman and Tatum 2006)

### 2.3.3 Framework based on sequential cascading coordination process.

Lee et al (2014) made a comparison on how information flows and shared among project participants during coordination activities. They made a comparison between parallel coordination process (Figure 5 and Table 1) and sequential cascading coordination process (Figure 6 and Table 2) using data exchange matrix analysis (DEMA) network notation. Their aim is to determine the most efficient method.

DEMA method was developed by building informatics group at Yonsei University, Seoul, South Korea. It was based on network analysis theory. A directed graph that shows an actor or a software application is the node with lines representing information flow. DEMA calculates the level of information exchanges between two actors.

Figure 5 shows the DEMA network of the parallel coordination process. An MEP coordinator and a general contractor (GC) were assigned the responsibility of coordination and he has the overall understanding of the project. They concluded that the volume of information overloads the GC-MEP coordinator, who is saddled with making decisions based on several uncoordinated models of drawing. The monopoly of knowledge is on the coordinator especially with regards the collection of reusable information from project participants (52%) and also has the highest percentage of reusable information (29%), see Table 1.

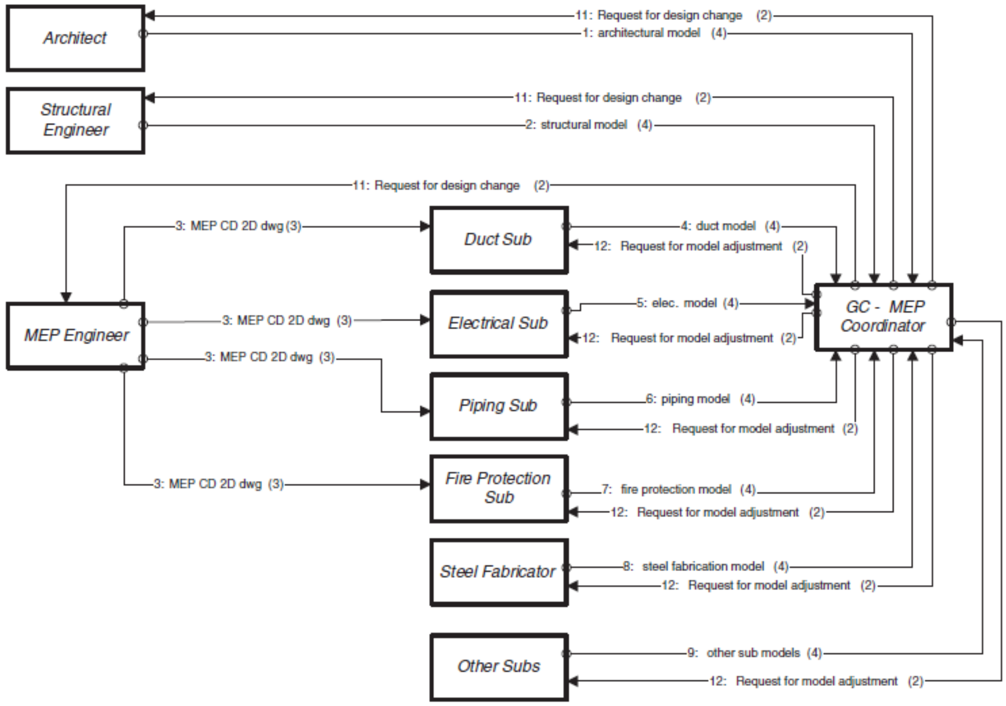


Figure 5 - DEMA network of the parallel coordination process (Lee, 2014)

Table 1 - DEMA network of the parallel coordination process (Lee, 2014)

| To / From | a) | b) | c) | d) | e) | f) | g) | h) | i) | j) | LDE (indegree) | nLDE (indegree) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a) Architect | | | | 4 | | | | | | | 4 | 6% |
| b) Structural engineer | | | | 4 | | | | | | | 4 | 6% |
| c) MEP engineer | | | | | 3 | 3 | 3 | 3 | | | 12 | 19% |
| d) GC-MEP coordinator | 2 | 2 | 2 | | 2 | 2 | 2 | 2 | 2 | 2 | 18 | 29% |
| e) Duct sub | | | | 4 | | | | | | | 4 | 6% |
| f) Electrical sub | | | | 4 | | | | | | | 4 | 6% |
| g) Piping sub | | | | 4 | | | | | | | 4 | 6% |
| h) Fire protection sub | | | | 4 | | | | | | | 4 | 6% |
| i) Steel fabricator | | | | 4 | | | | | | | 4 | 6% |
| j) Other subs | | | | 4 | | | | | | | 4 | 6% |
| LDE (outdegree) | 2 | 2 | 2 | 32 | 5 | 5 | 5 | 5 | 2 | 2 | 62 | |
| nLDE (outdegree) | 3% | 3% | 3% | 52% | 8% | 8% | 8% | 8% | 3% | 3% | | 100% |

The sequential cascading coordination process adopted a style of first starting with a small set of coordination of MEP subcontractors. The result is passed on to the next set of subcontractors, which result in the production of semi-coordinated models before the first coordinated meetings (Figure 6). This cycle ends at the end of the modeling exercise. These ensure less information's are with the general coordinator. Coordinated design information was also equally distributed among projects participants. Equal sharing of information enables individual project participants to develop a model from already coordinated models received from other participants (Table 2). The final model achieved in this method was more coordinated with fewer errors reducing coordinating time and cycles.

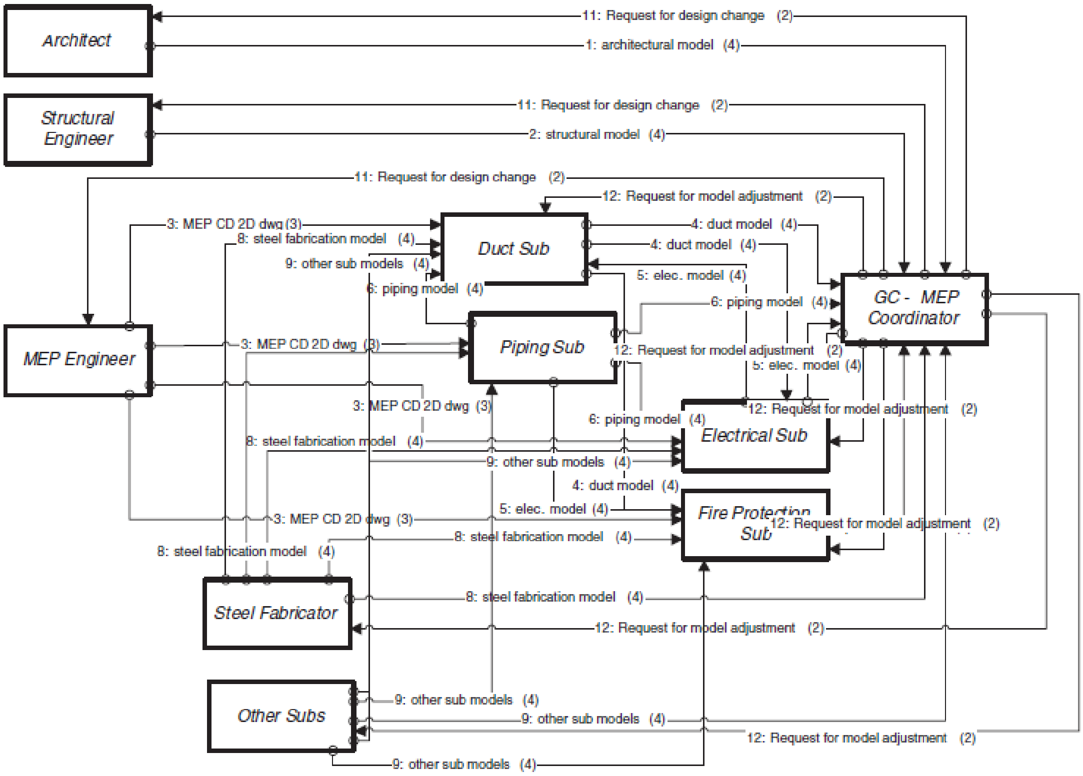


Figure 6 - DEMA network of the sequential cascading coordination process (Lee, 2014)

Table 2 - DEMA result for the sequential cascading coordination process (Lee, 2014)

| To / From | a) | b) | c) | d) | e) | f) | g) | h) | i) | j) | LDE (indegree) | nLDE (indegree) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a) Architect | | | | 4 | | | | | | | 4 | 3% |
| b) Structural engineer | | | | 4 | | | | | | | 4 | 3% |
| c) MEP engineer | | | | | 3 | 3 | 3 | 3 | | | 12 | 10% |
| d) GC–MEP coordinator | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 18 | 15% |
| e) Duct sub | | | | 4 | | | 4 | 4 | | | 12 | 10% |
| f) Electrical sub | | | | 4 | 4 | | 4 | 4 | | | 16 | 14% |
| g) Piping sub | | | | 4 | 4 | | | | | | 8 | 7% |
| h) Fire protection Sub | | | | 4 | | | | | | | 4 | 3% |
| i) Steel fabricator | | | | 4 | 4 | 4 | 4 | 4 | | | 20 | 17% |
| j) Other subs | | | | 4 | 4 | 4 | 4 | 4 | | | 20 | 17% |
| LDE (outdegree) | 2 | 2 | 2 | 32 | 13 | 13 | 21 | 21 | 2 | 2 | 118 | |
| nLDE (outdegree) | 2% | 2% | 2% | 27% | 18% | 11% | 18% | 18% | 2% | 2% | | 100% |

### 2.3.4 Framework to revise work process utilizing Building information model.

Korman et al. (2008) studied the current practice of building coordination and then improve and revise the process, utilizing Building information model. This process recognizes the constraints of current industry organization and therefore allow for separate and individual designs of building systems by specialist contractors.

As shown in Figure 7, the process starts with CAD files developed by individual specialist contractors from the Engineering drawings. Integration software is then subsequently used to merge the CAD files and 3-D models. To detect and identify physical interferences; a clash detection software application is activated.

Furthermore, the sequential style of identifying the interferences was recommended due to the type and limitation of software available. Because coordination of mechanical, electrical and plumbing can be challenging even in the most common buildings, they suggested the sharing of the model among the project team. This will ensure physical conflicts between structure, mechanical, electrical, and plumbing systems are identified early in the **design process** and resolution is expedited.

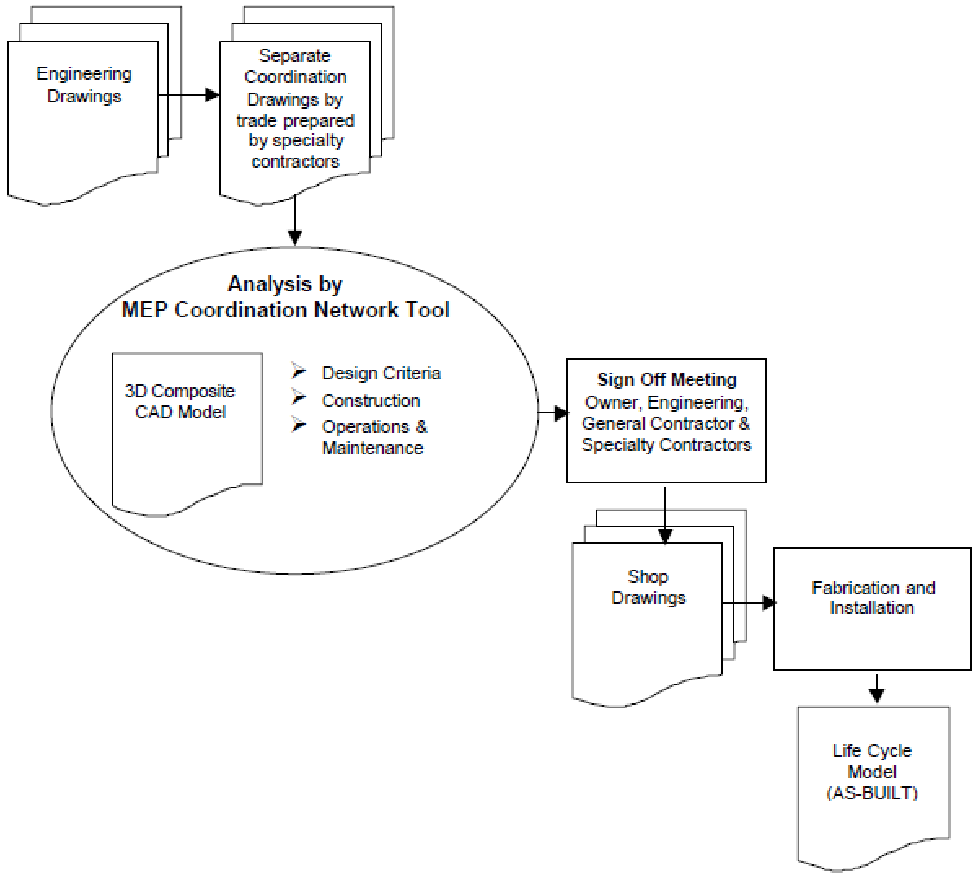


**Figure 7 -** MEP coordination using BIM (Korman et al. 2008)

### 2.3.5 Framework for a new BIM-enabled MEP coordination process for use in CHINA.

Yung et al. (2014) developed a BIM model to help in the MEP coordination solely in china. They used a ten step process guidelines that were suggested by Staub-french and khanzode based on US procurement practice. Although the model developed was based on the guidelines suggested, there was a slight change. This is due to the different design practices in china and because so many design institutes do not have 3D modeling capabilities. The process developed by Yung et al was made to include a 2D design step to accommodate the local practice situation. The 2D design was of cause not recommended for any published BIM guidelines, that aspect will be removed once BIM is widely embraced in the local industry practices in china.

They developed IDEF0 model in levels and level 1 has six main functions of the BIM-enabled design process. There is a major difference between the design practice in the US and China. Designing in the US involved multiple firms while in China just one design institute will be involved. The china system design coordination reduces coordination to within firm instead of coordination between firms.

The first function is the project plan. It's a stage where project idea is transformed into preliminary design solutions and project execution plan. The second function is the 2D concept design process where design solutions are developed into 2D concept design, including both 2D drawings and specifications. This second stage includes architectural, structural and MEP design.

The third activity is the 3D concept modeling's which is developed with the 2D concept design. Alongside the production of the 3D concept are the 2D design layout feedbacks. The 2D concept design information may not necessarily have the required details for modeling which will be identified by the modeler. The discipline-specific models will be developed in parallel and integrated into a full model. This conceptually demonstrates how MEP coordination is performed with BIM, according to this process of work in china.  Its interpret into facilitating coordination among designers by accommodating all of them into one big room.

The fourth function is 2D detail design. This stage involves the conversion of 2D concept design into 2D detail design. The fifth function produces the 3D details model and also conducts conflicts detections and makes recommendations. The recommendation is on how conflicts can be resolved. The last function is the constructability meetings which produces the conflict resolution ideas, final coordinated 3D models, and design.

### 2.3.6 Framework for coordination using BIM with cloud-based smart model

Sawhney and Maheswari (2013) proposed a framework for deploying BIM on the cloud platform or cloud computing (CC) to further enhance the design coordination especially clash detection. BIM being a data-rich, object-oriented digital representation of a facility. Data and views of the facility, appropriate to the designer's needs can be extracted and analyzed for decision making. In their paper, they explained the power of BIM is limited by numerous factors pertaining to people, process and technology. The industry is trying to solve the people and process issues via a variety of strategies that include; national BIM standards, standard contractual documents, and implementation roadmaps. For the technology aspects, cloud computing can provide many fundamental enhancements to the way BIM can be deployed and used in industry. Cloud computing is an umbrella concept to share information technology resources over the internet. Cloud computing basically is a technology used to flexibly access computational services offered via the internet. It offers software, platform and infrastructure.

Although BIM combines information's from multiple disciplines, allowing for faster and better information exchange which reduce coordination errors as shown in Figure 8. They argued that there are several practical limitations in using stand-alone BIM for the construction industry hence if BIM is deployed on the cloud it can further enhance the design coordination. They argued that as most of the time experts spend in transfer/exchange of large amounts of design data can be reduced extensively. Also, it further enhances the collaborative process that leverages web-based BIM capabilities and traditional document management to improve coordination.

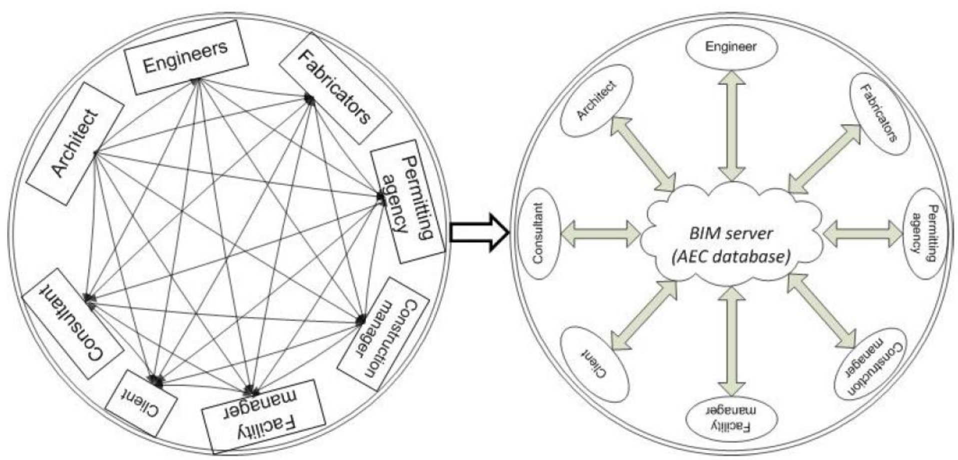


**Figure 8 -** Paradigm shift from file based exchange to BIM (Sawhney and Maheswari 2013)

They also envisioned three distinctive areas in which cloud computing can be functionally beneficial (see Figure 9). **The model server** can be used to host the central model of the building to allow inter and intra-disciplinary access seamlessly. **BIM software server** requires hardware resources to run which can be deployed in the cloud and shared efficiently between project participants. **Content management** serves as a perfect centralized and secured hosting environment for contents (data attributes / libraries) needed for BIM usage and deployments. The proposed cloud framework is shown in Figure 10.

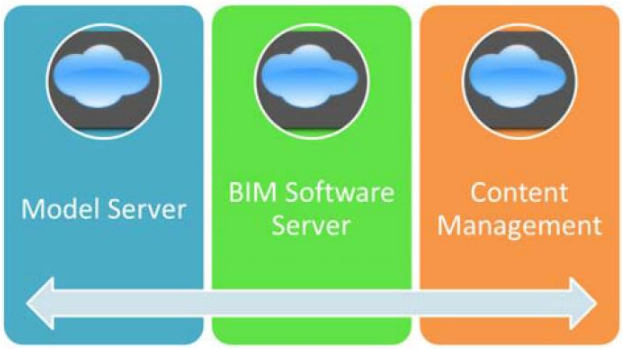


Figure 9 - Functional Benefits of Cloud Computing (Sawhney and Maheswari 2013)

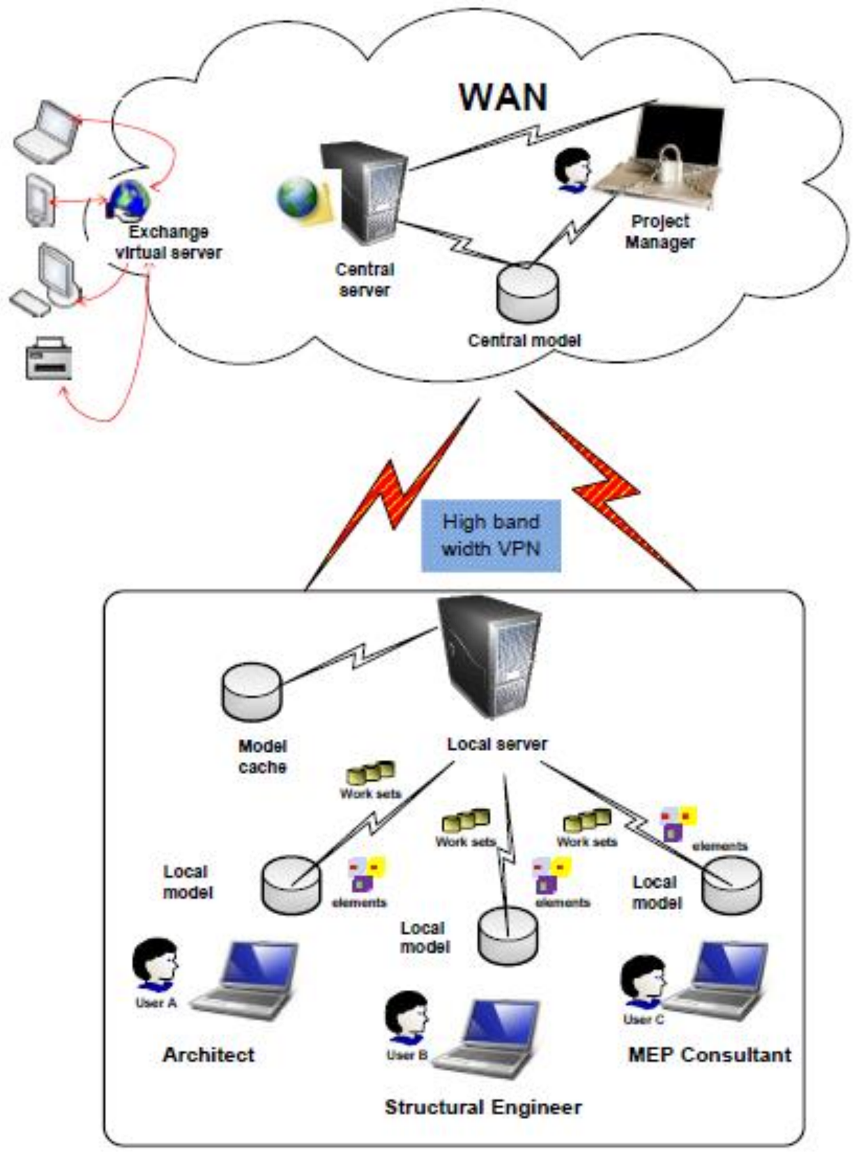


**Figure 10 -** BIM Cloud framework (Sawhney and Maheswari 2013)

### 2.3.7 Framework for exploring reasoning about relevant historical data to aid MEP resolution.

Wang and Leite (2013; 2015) noted that the advancement of information technology is changing the way people work, think and communicate. Hence, the process of identifying clashes has been expedited by formalized knowledge and advanced technology. The process of resolving MEP design conflicts is still very ad-hoc because it requires distributed knowledge from different trades to be integrated and collaborated for decision making.

Although most of the clashes discussed during the coordination meeting has repetitive patterns. The majority of knowledge involved was tacit knowledge based on specialized expertise and experiences. This type of knowledge is difficult, if not impossible to centralize or formalize. They noted that the information used and generated during the design review process was either not documented or not properly documented. The lessons learned from the review process was usually implicitly carried away by certain experts rather than shared with the project team for future benefits.

The lack of formalized knowledge for MEP design conflict resolution and inadequate historical data available hinders the attempts towards streamlining and expediting the decision-making process. Also, this impedes knowledge reuse and transfer across different disciplines (e.g., between design and construction) and different projects

They envision that by capturing and analyzing historical data relevant to coordination issues, tacit knowledge of MEP design conflict resolution can be semi-automatically extracted and formalized. This will reduce the reliance on individual researcher and provide efficiency in the process. They propose a new approach for formalizing knowledge in the MEP coordination process. Developed out of a sequence of three steps:

The first step is **attributed selection** which includes defining what the decisions to be made and what information needs to be captured. This will represent the rationale of decisions made. The second step was the determination of the **data documentation** which entails the efficient capture of the identified attributes values. Capturing will be in a model-based environment and ways to store the captured data for future reference and analysis will be determined. The final step is to explore different **reasoning mechanisms** for pattern recognition so as to identify a rationale for decision making.

### 2.3.8 Comparison between Traditional and BIM-Enabled Design Coordination in china

Wang et al (2014) made a comparison between the traditional style of design coordination and coordination with BIM in china. They were able to reveal the short comings of utilizing the traditional system with the aid of a life case study during the design development stage. The two case studies were similar building structure. Comparative data and information used were the one necessary to develop the first design model. Apart from the drastic shortening of the design development process (see Figure 11) the time necessary for the traditional design process requires additional four weeks than the BIM style of design processes. A performance analysis was conducted at the completion of the design processes to collectively determine the total number of errors encountered with both design process. Table 3 show the breakdown of all type of errors leading to clashes. The traditional design process coordination rely on completed design from all project participants, while the BIM system approach coordinates from the earliest form of design development process stage.

The study was able to reveal the advantages and contribution of BIM introduced at the early stage of the design development stage of the building design project coordination. It also reveal the improvements in terms of coordination duration i.e. 30% reduction, and ability to resolve clashes during design processes.

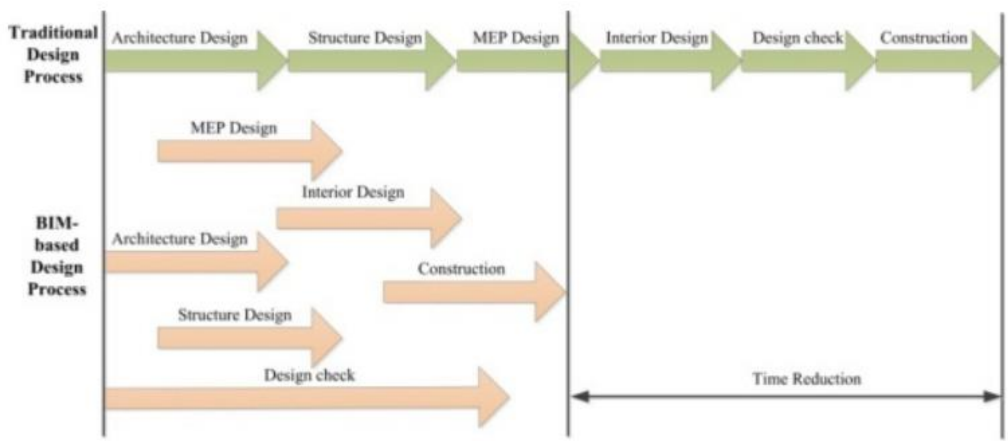


Figure 11 - Comparison between traditional design process and BIM-based design process (Wang et al. 2014)

Table 3 - Comparative analysis (Wang et al. 2014)

| | Traditional design method | BIM-based collaborative design |
|---|---|---|
| Architecture design errors | 23 | 15 |
| Structure design errors | 34 | 29 |
| MEP design errors | 40 | 34 |
| clashes between architecture and structure | 16 | 4 |
| clashes between MEP and structure | 224 | 45 |
| clashes between MEP and architecture | 55 | 16 |
| Total | 392 | 143 |

## 2.4 DISCUSSION

Literature relating to building services and coordination, the meanings, elements, professionals involved in the building coordination was presented in this chapter. Also the knowledge required in coordination, problems encountered during the process, as well as international research that has been conducted on coordination.

The whole exercise is aimed at acquiring knowledge about building services coordination process and practices. It is demanding to remove all errors that lead to conflicts from a building project because building coordination involves multiple disciplines of the different specialty. The building services coordination at the design development and review stage is the first stage of coordination of building projects. The building coordination process is the exercise that ensures all building services systems i.e. architectural, structural, mechanical, electrical, plumbing etc. are well synchronized and function effectively together. There are different approaches and methods to building services coordination. These approaches differ from use of a light table to more advance computerized software models. Most coordination exercises fall between these two methods. It was also revealed that there are many problems encountered during building services coordination such as; lack of knowledge and understanding of the multiple disciplines involved in building services coordination; lack of communication between designers, builders, and operation personnel; lack of understanding between the different MEP trades; difficulty to integrate construction knowledge into MEP coordination process; and high fragmentation of the coordination process.

The next chapter will describe the investigation of the current local practices during building service coordination in Eastern province of Saudi Arabia. This will be achieved through interviews with professionals from A/E offices in Eastern province. The purpose of the exercise is to understanding the current practices of building service coordination during the design and developmental stages.

# CHAPTER 3
# CURRENT LOCAL PRACTICES OF BUILDING COORDINATION

Overview of the current local practice in building design coordination during the design development and review stages was presented in this chapter. The interview investigation centered on the approach adopted during coordination, the duty of the professionals that makes up the coordination team, tools used in coordination and factors affecting coordination processes. The interview was conducted in selected architecture/engineering firms in Eastern province. This list has been provided by the Saudi Arabian Chamber of Commerce and industry.

## 3.1 METHODOLOGY OF INTERVIEWS

The Interviewees details are shown in Table 4. The interviews focused on the following issues:

1. Identifying the current processes of building services coordination during the design stages, and the tools adopted during these exercise.
2. Identifying the factors that affect the effective building services coordination during the design stages.

The interviews conducted were based on standardized structured questions (shown in Appendix 1).

**Table 4 -** Interviewed Architects.

| No | Name of the interviewed person | A/E firm or office | Region | Date of the interview | Method of the interview |
|---|---|---|---|---|---|
| 1. | Mr. Abdallah Hamdi (C.E.O) | Vision Engineering consultants (VADO) | Eastern (Al-Khobar) | 11/10/2015 | Face-to-Face |
| 2. | Mr Yahya Jawad S. Al-Najjar (Architect) | Al Raed Engineering Consultants | Eastern (Al-Khobar) | 12/10/2015 | Face-to-Face |
| 3 | Mr Ali Mohammed Al-Shakhil (Architect : Director) | AMS Architect & Engineering | Eastern (Dammam) | 13/10/2015 | Face-to-Face |
| 4 | Joseph A.Tinari (Director of Architecture) | Jacobs,Zamel & Turbag Consulting Engineers (JACOBS ZATE) | Eastern (Al-Khobar) | 18/10/2015 | Face-to-Face |
| 5 | Saleh M. Bamardoof (General Manager) | Al Raed Engineering Consultants | Eastern (Al-Khobar) | 21/10/2015 | Face-to-Face |
| 6 | Abdurahman Medallah (Senior Partner) | AKM & Partners. | Eastern (Al-Khobar) | 22/10/2015 | Face-to-Face |
| 7 | Taqiadden Almuntaser (Architect) | Assystem Radicon | Eastern (Al-Khobar) | 25/10/2015 | Face-to-Face |
| 8 | Shoeb Mohammed Siddiqui (Architect) | Saudi Technologist Consulting engineering. | Eastern (Al-Khobar) | 28/10/2015 | Face-to-Face |

| | | | | | |
|---|---|---|---|---|---|
| 9 | John Randy (Architect) | Saeed Nasser Architects. | Eastern (Al-Khobar) | 1/11/2015 | Face-to-Face |
| 10 | Abdullah A. Boshlibi. (Senior Executive Manager) | Afniah Consultants | Eastern (Al-Khobar) | 4/11/2015 | Face-to-Face |

The interviewees were asked about how coordination was conducted during the design and review stages of a building project. The responses of the interviewee are described in the subsequent sections:

## 3.2 FINDINGS OF THE LOCAL PRACTICE

Ten professionals were interviewed in a face-to-face session in their various office and the results of the interviews are summarized below:

### 3.2.1 Scope of Practice of Architectural Offices

The interview showed that the scope of practice of most architectural companies can be classified into two broad areas;

1. **Design and Engineering:** this includes architectural designs, civil and structural designs, MEP engineering design, interior design, urban design and planning. The companies mostly have all these professionals as in-house staff for various tasks.

2. **Management:** this includes project management, construction management and construction supervision. The interviewee are more involved with construction supervision and management than project management. Typically all the companies appoint a project coordinator on individual projects in-house. The project coordinator which is sometimes the project designer, coordinates all the task necessary to complete the building project.

### 3.2.2 Process of Building Design Coordination

The interview investigation revealed that the process of coordinating building services during the design stages are basically the same among the companies with slight differences at the initiation stage. Some companies commence coordination at pre-30% stage, some during the 30% or 60% stage. The process of coordination basically takes the following steps;

1. **Step 1:** concept drawings based on the clients brief will be developed, to include concept plans, elevations and 3-dimensional drawings, which will be approved by the clients. This activity will be conducted prior to 30 percent stage. Primarily, the architect is the only professional involved during this stage which includes deliverables such as schematic and concept drawings. The architect is also the design coordinator and in Saudi Arabia, different types of 2Dand 3D software are utilized. Building Information Modelling (BIM) software is rarely used.

2. **Step 2:** the improved design concept is discussed with the team of professionals at this stage (i.e. 30%). The coordination process is initiated in a series of formal and informal meetings about the proposed building design. Occasionally, a member of the professional team may work with other companies employed by the client or the consulting company. In this case, formal meetings are adopted. Also, email, video conferencing and telephone calls are constantly used as a means of communication. The professionals involved in this stage are:
    A. Architects: responsible for the architectural concept and detail designs.
    B. Interior Designers: responsible for interior fixtures and installations.
    C. Structural and Civil Engineers: responsible for structural components and specifications.
    D. MEP Engineers: responsible for all systems relating to mechanical, electrical and plumbing designs.
3. **Step 3:** step three involves continuous meetings with professional teams (informal & formal). This meeting will continue until the design completion stage (100%), this is to ensure that all data of individual team members are shared to prevent systems' clashes. The contract sometimes takes the form of design-build project. Companies that involve in such projects finish coordination after the completion of as built final drawings. Out of ten interviews conducted, only one company was involved in design build construction due to the existence of a construction arm of the company.

### 3.2.3 Significance of the Coordination Process

In Saudi Arabia the interviewees responded that the significance of the coordination processes during the building design stage is to ensure;

1. **Reduction in construction waste:** waste generated by alterations and corrections due to systems clashes are reduced. When coordination of the design stage is conducted efficiently, waste generated from systems clashes are reduced.
2. **Reduction in construction cost:** an effective coordination during the design stage will reduce the errors and corrections during construction, therefore extra costs that maybe incurred due to rework is reduced.
3. **Increases architectural quality of the building design:** during coordination, other professionals such as civil engineers may suggest the inclusion of new structural elements, this may also increase the architectural elements of the building design.
4. **Reduces all kind of specification misunderstanding:** the professionals involved during coordination will have an opportunity to explain in detail all specifications concerning individual specialties to other team members.
5. **Enhancement of all systems integration:** coordination will ensure that the all individual systems are carefully and effectively integrated with the help of the professionals involved in the coordination activities.

### 3.2.4 Issues Affecting Effective Coordination.

The interviewees responded that the issues affecting effective building design coordination are;

1. **Lack of structured processes:** this is an issue because design team professionals working separately and independently in different location will sometimes finish the project before submitting the design to the rest of the team. This is attributed to lack of structured processes.
2. **Lack of collaboration between professionals:** the professionals conducting the coordination activities occasionally work independently which consequently affects the coordination process.
3. **Lack of imaginative skills from the professional:** the professionals in the team that lacks imaginative skills will find understanding and interpreting architectural design concept difficult. Lack of this skill may lead to wrong interpretation of building design which will cause errors.
4. **Different office location for coordination team members:** when professionals in the coordination team are not located in the same office, informal meetings cannot be done. The gap caused by offices located in different regions will have an effect on the process.
5. **Client's unclear information, misinformation, and interference:** unclear client's information or misinformation will lead to wrong design proposals which will later be corrected after much coordination input. Interference by the client

either for a change of brief or lack of fund at a later stage of coordination will also affect the process of coordination negatively.

6. **Payment and remunerations:** coordination can be affected negatively if payment and remuneration for professionals conducting the exercise is delayed or stopped. If payments and remuneration are delayed professionals will not be encouraged to perform efficiently during the activities. This issue will cause some professionals not to participate in the coordination activities.

### 3.2.5 Consequences of Ineffective Coordination

The interviewees responded that the consequences of ineffective building design coordination are:

1. **Installation problems:** conflicts will occur during systems installation on site, leading to challenging and difficult corrections. The problems are the repercussion of inefficient coordination during the design stage.
2. **Extension of project timelines:** poor coordination will cause repeated correction during the construction stage. The frequent correctional activities will increase the time duration allotted for construction.
3. **Increased scope of work:** scope of work is the total amount of work need to complete the whole construction. The scope of work will be increased proportionally to the volume of correction and reconstruction conducted on a building project.

4. **Increased contractor change orders:** the errors in the construction documents lead to increased contractor change order. Increase change order subsequently increase monies paid to the contractor
5. **Shared systems errors:** a building is a composition of different systems and all the systems are interrelated. Errors made in a particular system will spread to another system. For example, an error made on the architectural and structural system will affect the spaces and clearances of the MEP systems.

### 3.2.6 Means of Receiving Error Feedback

The interviewees responded that the various means they employ to receive feedback of consequences of ineffective building design coordination are:

1. **Snag list received through email from contractors:** contractors typically compile a list of errors identified during construction work progress and subsequently present it to the design office through a communication channel.
2. **Meetings attended by construction professionals:** construction professionals periodically attend meetings held during the construction project and challenges/errors are discussed with supervisor's representing the design office.
3. **Quality survey:** quality teams are saddle with the responsibility of compiling all construction complains on a project by working closely with the contractor. The quality team also works closely with the coordination team, basically serving as intermediary between the coordination team and the contractors.

4. **Complains from contracting professionals:** the construction companies sometimes send their representatives directly to the design firm to complain about error encountered.
5. **Site engineers submitted reports:** the design company are sometimes involved with the project up to the construction stage. In such contracts, the company appoints a site engineer/supervisor that communicates the errors detected on site with the coordination team.

### 3.2.7 Means of Improving the Coordination Process

The interviewees responded that the various ways to improve building coordination processes are:

1. **Clarity in the client brief and information:** from the briefing stage of the design process the client's brief must be clearly understood by the design professionals. All information must be clarified to ensure that decisions made during the various design stages are aligned with the client's expectations.
2. **Improved coordination tools and management skills:** the design coordination process should adopt the latest design tools available. The more advance the tool adopted in coordination is the higher the tendency of eradicating all forms of error during design coordination. An improved managerial skill of the coordinator will also add to a smooth process in the various coordination phases.
3. **Avoidance of client's middle disruptions of project phases:** the designers must ensure the prevention of any client interference during the process. Such

interference will cause disruption of the smooth process of the design coordination activities. All relevant information should be collected from the client during the briefing stage to avoid disruption.

4. **Responsibility and accountability for decisions:** professionals participating in the coordination activities must be made to be responsible for the decision taken during the exercise. When accountability is ensured individual team members will consider the consequence of their actions during the process.
5. **Employment of experienced professionals:** experienced professionals should be assigned the responsibility of conducting building services coordination. With the employment of experienced teams, typical errors on typical projects will be avoided during coordination easily.
6. **Using requirement checklist:** a checklist for each system can be adopted during the process to ensure all requirements are attended to during the exercise. The checklist will serve as a guideline for steps to take during coordination phases.
7. **Improved standardized remuneration:** the fees and remuneration paid to design professionals on building design projects should be standardized and proportional to the task. The standardized method adopted in North America can be adopted to ensure a more committed professional coordination team.
8. **Guideline to coordination and management:** the interviewees suggested that a guideline can be developed for the A/E companies to manage effectively coordination and management processes.

## 3.3 DISCUSSION

This section explained the process of the current local practice of building services coordination during the design and review stages in the Saudi Arabian A/E industry. It describes the scope of practice of design offices, steps followed during building designing coordination, the significance of the coordination processes, issues affecting effective coordination, consequences of ineffective coordination, means of receiving error feedback and strategies for improving coordination processes.

The interviews showed that;

1. Scope of practice of most A/E offices in Eastern province of Saudi Arabia are sub-divided into:
   a. Design and engineering services.
   b. Management of projects.
2. Process of building design coordination consist of three steps:
   a. Step 1: Concept design.
   b. Step 2: Coordination activities initiations.
   c. Step 3: Continuous meetings to completion.
3. Significance of the coordination process are:
   a. Waste reduction
   b. Cost reduction
   c. Improvements in design qualities.
   d. Better understanding.
   e. Increased building systems integration.

4. Issues affecting effective coordination are:

    a. Lack of collaboration between professionals.

    b. Lack of management skills.

    c. Team members working from the different location.

    d. Unclear information.

    e. Lack of adequate payments and remunerations.

5. Consequences of ineffective coordination are:

    a. Installation problems.

    b. Increased project timelines

    c. Increased scope of work

    d. Increased contractor change orders

    e. A system error affects all other systems

6. Means of receiving site error feedback includes:

    a. Compilation of snag list.

    b. Periodic meetings.

    c. Quality surveys.

    d. Professional complaints.

    e. Site reports.

7. Strategies for improving processes of coordination are:

    a. Clear information.

    b. Improved management skills.

    c. Prevention of client interruption.

    d. Responsible for decisions.

e. More experienced team members

f. Requirements checklist.

g. Increased professional remuneration.

The next chapter presents the list of factors affecting building coordination processes during the design and review stages. Identification of the factors was done by investigating various international literature in building design coordination and through interviews conducted among the architectural design offices.

# CHAPTER 4
# FACTORS AFFECTING BUILDING SERVICES COORDINATION

Analysis of the factors affecting the process of building services coordination is important for the development of the framework, aiming at increasing the effective coordination of building services during the design development and review stage. The process of identifying the factors was through research into many pieces of literature on building services coordination and knowledge obtained through information gathered from local professional practices. Thirty-six factors that can affect the processes of effective coordination was identified.

## 4.1 FACTORS RELATED TO THE PLANNING PHASE OF THE PROJECT

### 4.1.1 The scale and complexity of the project

The scale and complexity of a project are amongst the factors that influence building services coordination (Korman and Tatum 2001; Chiu 2002). As the size of a project increases, the design effort required increases (Thomas et al. 1999), the quantity of parametric three-dimensional modeling required is significantly increased (Sacks and Barak 2008), and thus, ultimately difficulties and complexity in coordination is a potential risk (Chang and Ibbs 2006).

### 4.1.2 The schedules of the project

Project schedules dictate the time duration for various stages of a project delivery cycle. Project schedules have been identified as a factor that influences MEP coordination productivity (Korman and Tatum 2001; Ashuri et al 2014; Medallah 2015). Design companies engaged in the parallel delivery of multiple projects are usually characterized by hurried schedules and pressurized professionals. These conditions are potential causal factors for poor design coordination (Al-Shakhil, 2015; Medallah, 2015).

### 4.1.3 The allocated budget for the project

The cost of a project is a key determining factor in the recruitment of professionals for a project. It also has a significant influence on the type of specification and elements adopted for the building design (Pennanen et al. 2011). Subsequently, project cost (value) is an important factor that affects coordination exercise (Medallah 2015).

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### 4.1.4 The location of the project

A project location is characterized by climate, weather and its unique site conditions, these influence design elements, structural components, and the type of engineering design and installations that will be used (Hamdi 2015). Thus, the coordination of MEP systems is potentially linked to the location of a project (Ashuri et al. 2014). Project location influence and determine the professional composition of the design and building coordination team (Siddiqui 2015).

### 4.1.5 Availability of clear Architectural program

Architectural programming, also known as design briefing articulates the client's requirements during the project planning stage. In this stage, the project definition and significant decisions concerning the projects are made (Yu et al. 2006). A clear architectural program facilitates a clear understanding of the needs and requirements of the client, this will subsequently ensure smooth design and coordination process (Ryd 2004).

## 4.2 FACTORS RELATED TO THE DESIGN OF MEP SYSTEMS

### 4.2.1 The quality of the preliminary/concept design of the building project

The preliminary design quality required by the client should be detailed in the architectural program. Despite this, errors or mistakes are bound to be made in the preliminary design; this is usually transferred to the coordination stage (Boshlibi 2015). Thus, achieving the desired design quality is a significant factor that influences MEP services coordination (Ashuri et al. 2014; Korman and Tatum 2001).

### 4.2.2 The type and occupancy requirements of the building project.

The type of building design and occupancy requirements required by the client are factors that influence the type and density of MEP systems to be selected (Riley et al 2005). This characteristic feature is one of the main factors affecting coordination efforts and cost (Korman & Tatum 2001). Some of the issues that may have a potential influence on MEP services coordination include flexibility and adaptation considerations (Israelsson and Hansson 2009) and design considerations for intelligent buildings (Sommerville and Craig 2010).

### 4.2.3 The design complexity of the MEP systems for the building project

MEP systems design includes equipment's requirements, systems' components' location and component routes in the building (Ashuri et al. 2014). The design complexity of these systems has a direct implication on the difficulties encountered in the coordination process (Ashuri et al. 2014).

### 4.2.4 The process of exchanging data, information and design output among MEP systems

The process of exchanging data, information and design outputs among MEP systems is a factor that affects MEP coordination productivity (Chiu 2002; Ashuri et al. 2014). Common interoperability issues include syntactic problems or programmatic errors in a building design (Lee et al. 2015). The effect of issues caused by interoperability during coordination could amount to losses in billions of dollars (Senescu et al. 2006).

### 4.2.5 The aesthetic required when integrating the MEP systems into the Architecture and structural systems

Aesthetic requirements must be preserved in the process of integrating the MEP systems into the architecture and structural systems. This consideration influences MEP coordination (Korman and Tatum 2000; Korman et al. 2003). The various professionals involved in the coordination process presents some difficulties; this is due to the need to strike a balance between aesthetic requirements and the functional aspects of the systems (Wilkins and Kiviniemi 2008). Thus, in the process of routing and spatial arrangement of MEP systems, priorities have to be decided on between aesthetic considerations and potential clash points (Bhatla and Leite 2012).

### 4.2.6 The cost of the specified MEP systems for the building projects

The cost of the specified MEP systems for the building projects also referred to as MEP contract cost affect the level of effort during MEP services coordination (Korman and Tatum 2000; Riley et al. 2005; Ashuri et al. 2014).

### 4.2.7 The performance of the MEP systems specified for the building project

The function and performance of designated components for building services specified for the building project affects the process of coordination (Korman et al 2003; Riley et al 2005; Tabesh and Staub-French 2005). This is due to increase in user requirements for MEP systems, and hence an increase in functionality demands and types of systems to be installed. This requires specialty contractors for installation and thus, it affects the coordination processes (Korman and Tatum 2006a,2006b).

### 4.2.8 The detailing of various components of the MEP systems.

The detailing of various components of MEP systems determines how its various parts will be interconnected. The connection style and structure type (steel and concrete) are key aspects in the determination of the details for fixing and installation (Korman and Tatum 2006b). Thus, the connection and detailing considerations are essential aspects of MEP coordination (Yung et al. 2014; Korman and Tatum 2006a,2006b).

## 4.3 FACTORS RELATED TO THE CONSTRUCTION OF MEP SYSTEM

### 4.3.1 The material used in fabricating the MEP system specified for the building project

Material type refers to designated materials used for specific components; these include aluminum, galvanized steel, sheet metals, stainless steel and fiberglass. Material types determine how pipes, ductwork, and electrical systems will be installed in tight spaces which are mostly difficult to detail, maintain and construct. This is due to possible tensions between MEP spaces, usable floor spaces and ceiling height (Riley 2000). thus, the material used in fabricating the MEP systems is amongst the factors that influence the coordination process (Korman and Tatum 2000; Riley 2000).

### 4.3.2 The required clearance for the MEP systems specified for the building project

The required clearance for MEP systems for purposes of insulation and installation is a key factor considered during building services coordination (Korman and Tatum 2000).

This is due to difficulties that arise during building services systems installation and organization into different spaces and levels (Leaman and Bordass 1993).

### 4.3.3 The connection support used during installation of the MEP systems

The connection support used during installation of the MEP systems consists of designated systems adopted for the support of various components. This may include pipe rack or trapeze hangers used for holding electrical conduit pipes to the wall. These support systems influence the ease of routing through architectural and structural elements, and thus this interference is a typical problem encountered during MEP coordination (Korman et al. 2003 ; Korman 2009).

### 4.3.4 The space allocated for the installation of the MEP system in the building

The space allocated for the installation of the MEP systems in the building is critical for building services coordination (Korman et al 2003; Riley 2000). Inadequate spaces could impair the installation and maintenance of building systems (Riley 2000). Installation spaces include spaces reserved for the installation of components, spaces surrounding components for construction craft persons, material handling, storage and construction equipment (Korman et al 2003). A space requirement of 5ft from the end of a conduit pipe for electrical cables is an example of how installation considerations can affect building services coordination (Riley 2000).

### 4.3.5 The allocated time for fabrication of the MEP systems components

The allocated time and cost for the fabrication of the MEP systems are factors considered in building services coordination (Korman and Tatum 2000). The cost and time of fabrication considerations influence the choice of building systems, the delivery time and fabrication schedule. This results in inefficient coordination during the design stage and ultimately changes in design during the procurement phase (purchasing and subcontracting) (Korman and Tatum 2006a; Wan and Kumaraswamy 2012).

### 4.3.6 Testing requirements of MEP systems during construction

The relationship between all building systems is influenced by start-up and testing requirements of its individual systems. Thus, start-up and testing requirements of components are factors considered during the coordination process. This involves the schedule and the process of start-up and testing of the components which influence the decisions and choices made during the coordination process (Korman and Tatum 2000; Yung et al. 2014).

### 4.3.7 The installation sequence of the MEP systems

The AEC industry is a sequence of interconnected activities. The installation sequence of MEP systems determines the priority of installation and thus, influences the coordination process. To maximize the efficiency of coordination during the design stage, the typical installation process for systems and the group of systems should be considered and prioritized (Korman and Tatum 2000; Korman et al. 2003).

### 4.3.8 Safety considerations during the installation of the MEP systems

The increasing complexity of MEP systems results in a corresponding increase in the scope of safety requirements considered during coordination processes (Sacks and Barak 2008; Korman & Huey-King 2014). Such complex systems are used for the distribution of electrical energy, communication, provision of water, waste disposal and safety of the inhabitant (Korman and Tatum 2006b; Korman et al. 2010). The interwoven dependency of these building systems is a factor that influences their coordination (Tabesh & Staub-French 2005).

## 4.4 FACTORS RELATED TO THE OPERATION AND MAINTENANCE OF MEP SYSTEMS.

### 4.4.1 Access to the various components of the MEP systems

An effective O/M influences building performance, thus adequate space provisions should be made for O/M of installations such as HVAC sheet metals, sanitary drainage system, HVAC process piping, manufacture process piping, fire protection, water distribution, electrical systems, control systems and telephone/data communication (Lai and Yik 2007). The accessibility of maintenance personnel to specified components for O/M should be defined and reserved, this is crucial for consideration during the coordination process (Korman and Tatum 2006b).

### 4.4.2 Safety requirements during the operation and maintenance of the MEP systems

Safety requirements for O/M of building systems is a determinant factor that affects decisions taken during the coordination process (Korman and Tatum 2000; Sacks and Barak 2008). Safety standards and regulations must be followed and all information regarding safety issues must be considered with implications. Furthermore, complex buildings require periodic maintenance to ensure its integrity and safety. The complexity of the building will determine the type of installation required to conduct the required maintenance. In facilities such as a nuclear facility, O/M could present potential harm to human life. This emphasizes the need for detailed consideration of safety measures (Luk et al. 2007).

### 4.4.3 The expandability and retrofit requirements of the MEP systems' components in the building.

Expandability and retrofit requirements can improve energy efficiency, increase productivity, reduce maintenance cost and improve the thermal comfort of buildings (Ma et al. 2012). Expandability and retrofitting characteristics of systems are important criteria during O/M of a facility. Issues such as the extent of retrofitting and how it affects structural and technical systems of the building would arise during coordination (Zavadskas et al. 2008). Thus, the flexibility of a system in relation to expandability and retrofitting will affect its selection and specification during the coordination process (Korman and Tatum 2000).

### 4.4.4 Availability of the spare parts required for the maintenance of MEP systems

The availability of the spare parts required for the maintenance of MEP systems influences the duration of downtime (Arditi and Nawakorawit 1999). In consideration of the maintenance processes during the design phase, the spare part availability of specified systems should be considered (Korman and Tatum 2000). In cases where the required spare parts have to be ordered from outside the country, it takes a long time before it delivery. Such issues should be adequately considered (Al-Shakhil 2015).

### 4.4.5 Availability of Building management systems (BMS)

The adoption of BMS for the centralized management of all integrated building systems will influence the coordination process. To achieve a sustainable design, the adoption of a building management system should be considered during the building design stages. The O/M manager employs BMS to facilitate a robust management of building systems to improve efficiency during the occupancy stage of the building (Clark and Mehta 1997; Derek and Clements-croome 1997).

## 4.5 FACTORS RELATED TO THE OWNER

### 4.5.1 The clarity of the requirements and objectives provided by the owner

The clarity of the building owner's requirements (or EIR) and project objectives is an essential factor during the design stage. Thus, the systematic identification and clarification of all owners' requirements are crucial to a successful design. This can be achieved through an architectural program which consists of the preparation, information, analysis and evaluation of all owner's requirements (Shen et al. 2004). As owners requirements vary and increase, more demands will be made of design professionals, this might further result in an ineffective exchange of information between project owners and building professionals (Masterman and Gameson 1994).

### 4.5.2 The type of project ownership

The owners of a building project can be categorized into public ownership or private ownership and the either of the two affect coordination differently. Public owned projects are more characterized by delays caused by governmental policies and professionals invariably become less interested in coordination processes of public owned projects (Bamardoof 2015). Coordination of privately owned projects is less complex to manage than public owned projects (Medallah 2015).

### 4.5.3 The frequency of alterations demanded by the owner

Design changes and alterations demanded by the project owner is identified as a factor that influences building services coordination (Medallah 2015; Bamardoof 2015). The consequence of design changes is a carried over effect to all design deliverables. Aside an increase in the scope of work, project cost and timeline; the design coordination process is also influenced by frequent changes (Olawale and Sun 2010). Alterations of the design could be as a result of many reasons. Significant amongst these are unclear information from the clients; clients' change of needs; changes in technology; design professionals working from different locations; constructability issues; project delivery timeline; and payments (Al-Shakhil 2015; Bamardoof 2015; Medallah 2015).

### 4.5.4 The project delivery system adopted for the building project

The type of project delivery system employed will influence MEP coordination during the design stage (Korman and Tatum 2000; Park et al. 2014). Project delivery systems refer to the style and manner of approach to executing the building project. The traditional project delivery systems in the construction industry are construction management at risk, design-build and design-bid-build (Konchar and Sanvido 1998). Recently the sustainable design paradigm shift has resulted in an integrated design and project delivery process called Integrated Project Delivery (IPD). This allows the involvement of all parties involved from the inception of a project to its occupancy stages, and thus facilitates the coordination processes (Hellmund et al. 2008; Medallah 2015).

### 4.5.5 Honoring agreed upon payments schedules

Dishonoring agreed upon payment schedules could slow down the coordination process which in turn influences the delivery timeline of the building design project (Medallah 2015). Delay in the progress of payments by the owner is one of the main factors that cause the delay in building construction projects (Assaf and Al-Hejji 2006; Sambasivan and Soon 2007; Sweis et al. 2008).

## 4.6 FACTORS RELATED TO THE DESIGN TEAM AND TOOLS USED

### 4.6.1 The level of experience of the design team

The collective level of experience of the project team members is a crucial factor that influences coordination activities (Tinari 2015;Boshlibi 2015). Disproportionate levels of experience of team members' results in varied viewpoints and subsequently leads to ineffective collaboration among coordination team members. A project coordination team is a collection of people brought together to achieve a specialized task of a multidisciplinary nature (Ammeter and Dukerich 2002). Teamwork is a basic feature in the AEC industry, and thus, the efficiency of the industry is increased when team efficiency is increased (Senaratne and Gunawardane 2015).

### 4.6.2 The capacity of the firm handling the project

The size and overall configuration of a firm influence the level of efficiency of coordination (Tinari 2015). Design firms are established in different sizes with professionals from different backgrounds, training, and levels of experience. Smaller firms employ freelance professionals to execute their building projects while larger firms are characterized by various departments dedicated to various types of projects (Bamardoof 2015).

### 4.6.3 The comprehensiveness of the software utilized for the building design

The coordination process has evolved from the paper-based sequential comparison overlay process (SCOP) to 3D CAD. This will surely have a tremendous influence on building systems coordination. The combination of object-oriented 3D models and knowledge-based reasoning structures increases the efficiency of the coordination process (Park et al. 2015; Chiu 2002; Korman and Tatum 2000). While SCOP requires the contribution and continuous supervision of experienced teams, 3D CAD enables coordinators to view spaces in solid models which enhance the detection of errors and inconsistencies (Singh et al. 2015).

### 4.6.4 The software literacy level of the design team

The competency level of utilizing the software and technology adopted for coordination is key to the success of the coordination process (Hamdi 2015;Medallah 2015). The lack of trained professionals in modern software technology is one of the key factors hindering the adoption and implementation of these technologies (Arayici et al. 2011; Ku and Taiebat 2011). Inadequate knowledge of available technology results in an inefficient coordination process due to lack of its proper application by members of the design team (Liu et al. 2010).

### 4.6.5 Communication skills of the design team members

Communication is the ability to interact effectively with other professionals participating in the coordination process (Odusami 2002). Communication is central to the success of the coordination processes (Chiu 2002; Medallah 2015). Effective communication improves the quality of delivery and sharing of information during coordination (Korman 2010).

## 4.7 DISCUSSION

The investigation of the factors influencing the process of effective coordination of the building services systems during the design and review stage was achieved by literature studies and interviews from practicing professionals. Identification of the factors is necessary for evaluation through questionnaire survey and subsequently aid the development of the proposed framework.

The chapter presents thirty set of factors that potentially affects the processes of effective building services coordination during the design and review stages. These factors were classified under five categories related to the design criteria and intent, constructional issues, operations and maintenance, coordination teams and project managements.

The next chapter is about the questionnaire data analysis and the results derived from the data. The thirty-six factors affecting coordination was used to develop into a questionnaire and distributed among professionals in Eastern province. Lastly, the agreements between the professionals was tested.

# CHAPTER 5
# ASSESSMENT OF THE FACTORS

Thirty-six factors influencing the process of effective coordination of building services during the design development and review stage was identified through a process explained in chapter four. The testing and administration of the thirty-six factors identified was conducted through a questionnaire survey described below:

## 5.1 DEVELOPMENT OF QUESTIONNAIRE SURVEY

The questionnaire survey developed was distributed among architectural, engineering, construction and facilities management companies in the eastern province of Saudi Arabia. The questionnaire consists of two main parts (see Appendix 2):

Part 1: information regarding the respondents' professional practice, areas of expertise and levels of experience.

Part 2: categories of the identified thirty-six factors and level of assessments.

### 5.1.1 Identification of the Population and Sample Size

The population of architectural, engineering, construction and facility management companies in Eastern province of Saudi Arabia was obtained from the Saudi chambers of commerce. The total number of registered companies includes 64 architecture consulting offices, 13,000 construction companies and 1,200 facility management (O&M) companies. Due to government policy, details of 64 architectural companies, 200 construction companies, and 200 facility management companies was released for the study. The sample size equation in chapter one was adopted (equation 1.1 and 1.2).

Using the data collected, architects n = 18; contractors n = 22 and facility managers n = 22, however, 30 responses were collected from 30 architects, 30 contractors, and 30 facility managers.

### 5.1.2 Pilot Testing of the Questionnaire Survey

Prior to the questionnaire survey distribution, a pilot testing of the initial draft was directed among a sample of architectural companies in Eastern province. The testing was conducted to achieve:

1. The adequacy of the questions in the survey.
2. Identification of ambiguities in the survey.
3. Incorporating additional factors if required.
4. Reviewing spaces, gaps, and punctuations for each question.
5. Estimating the time required for filling questions.

After the exercise, the questionnaire draft was amended based on observations highlighted by the professionals. The initial draft contains thirty-two factors that affect building services coordination, after the pilot testing the factors increased to thirty-six.

### 5.1.3 Distribution of the Tested Questionnaire Survey

The questionnaire survey was distributed to 30 architectural design companies, 30 contractors and 30 facility management (O/M) companies in the Eastern Province of Saudi Arabia. This was for the purpose of assessing the importance of the identified 36 factors. The respondents were asked to indicate the level of importance of the selected factors in the questionnaires through the selection of five evaluation terms: ‘Extremely Important’, ‘Very Important', ‘Important’, ‘somewhat important' and ‘Not Important'. 90 questionnaires were received for data analysis.

### 5.1.4 Data Analysis

This chapter present the analysis of the survey data received from 30 architectural design companies, 30 construction companies, and 30 facility management (O/M) companies. The data is categorized into two main sections;

A) General information of respondents.

B) Factors identified for assessments.

## 5.2 GENERAL INFORMATION OF RESPONDENTS

This section presents the analysis of the general information section of the questionnaire survey. After analyzing the data the results was interpreted in percentages, graphics, and summarily explained.

### 5.2.1 Respondents Experience

All the respondents were asked to fill out their level of experience in a section of the questionnaire survey. The work experience section was divided into four categories: ‘Less than 5 years', ‘5-10 years', '10-20 years' and ‘Over 20 years'. The experiences analysis are;

**Architects Work Experience**

The architects experience data indicate that 50% of the architects respondents have between 10-20 years of work experience (15/30), 23% of the respondents have between 5-10 years of work experience (7/30), 20% of the respondents have over 20 years of work experience (6/30), and 7% of the respondents have less than 5 years of work experience (2/30). All respondents’ results are shown in figure 12;

**Contractors Experience**

The contractors experience data indicate that 50% of the contractors respondents have between 5-10 years of work experience (15/30), 20% of the respondents have less than 5 years of work experience (6/30) , 17% of the respondents have over 20 years of work experience (5/30), and 14% of the respondents have between 10-20 years of work experience. All respondents’ results are shown in Figure 12;

**Facility Managers Experience**

The facilities managers experience data indicate that 40% of the facility managers respondents have between 10-20 years of work experience (12/30), 37% of the respondents have between 5-10 years of work experience (11/30), 13% of the respondents have less than 5 years of work experience (4/30) and 10% of the respondents have over 20 years of work experience (3/30). All respondents' results are shown in Figure 12;

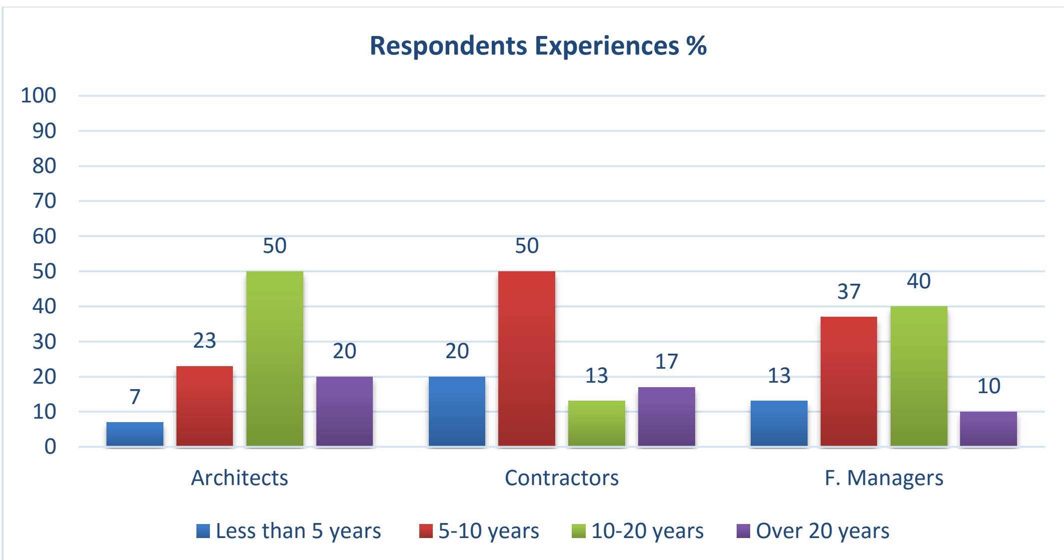


Figure 12 - Respondents Experience %

## 5.2.2 Type of Projects worked on by Respondents

The various types of projects presented to the respondents include high-rise residential building projects, low rise residential building projects, educational building projects, office building projects, recreational building projects, sport building projects and commercial building projects.

**Projects mainly worked on by Architects/Design coordinators**

The respondents results (Figure 13) reveal that 30% (9/30) of the design coordinator worked on high rise residential building projects; 90% (27/30) of the design coordinator respondents worked on low rise residential building projects; 77% (23/30) of the design coordinator respondents worked on educational building projects; 83% (25/30) of the design coordinator worked on office building projects; 37% (11/30) of the design coordinator worked on recreational building projects; 23% (7/30) of the design coordinator worked on sports building projects and 90% (27/30) of the design coordinator worked on commercial building projects. 17% (5/30) of the respondents indicated that they worked on interior design projects, industrial building projects, Islamic building projects, aviation projects, military building projects and cultural building projects.

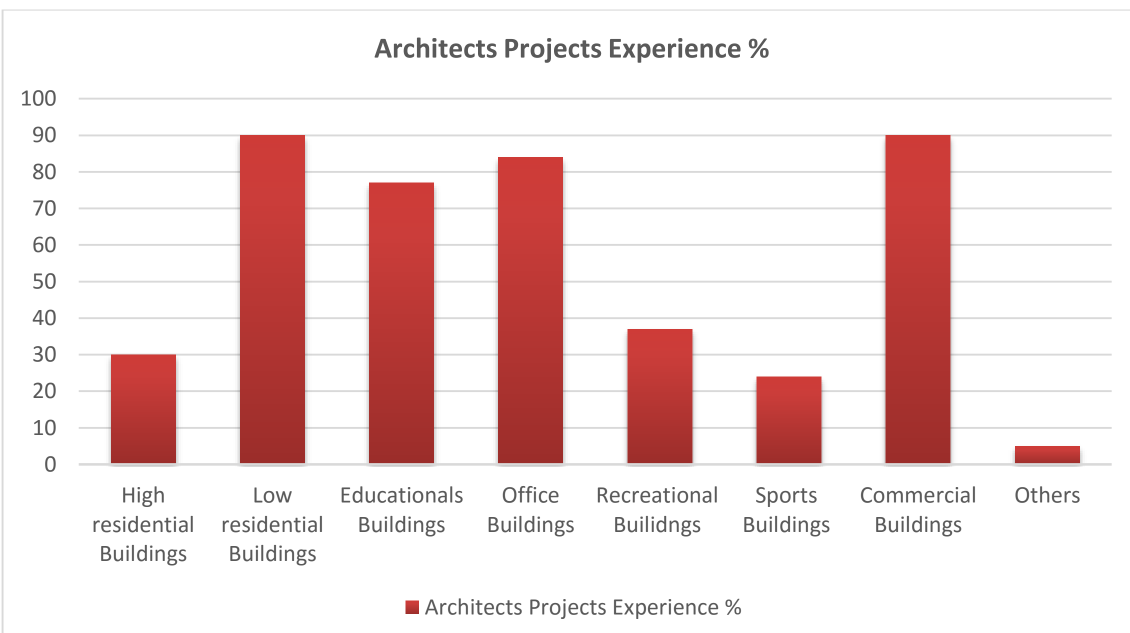


Figure 13 - Projects executed by Architects

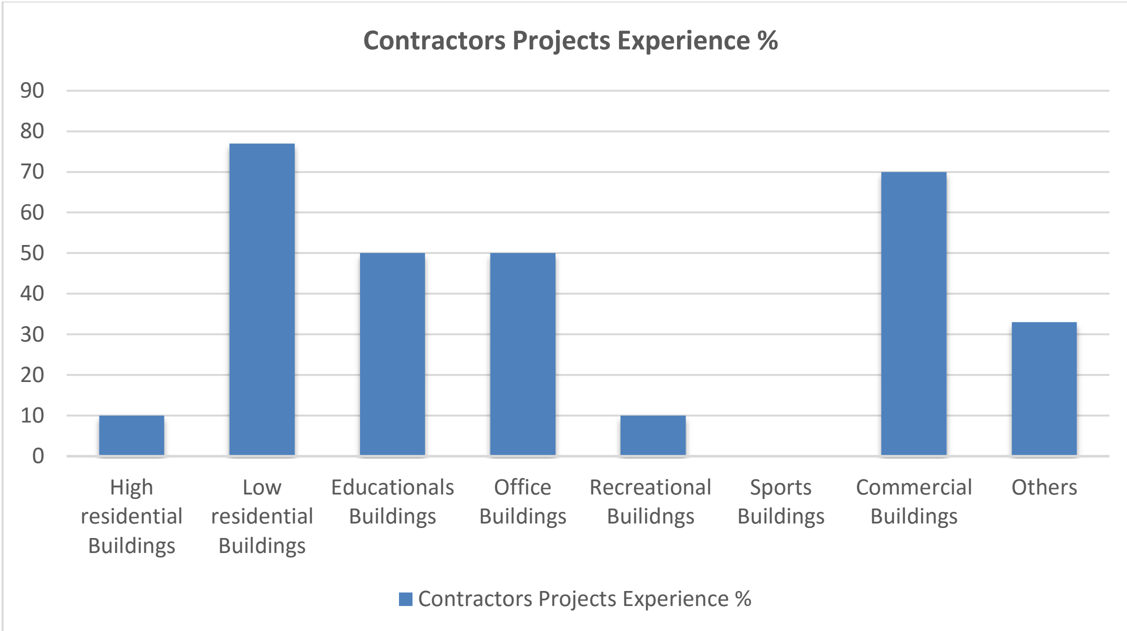


Figure 14 - Projects Executed by Contractors

**Projects mainly worked on by Contractors**

The contractors questionnaire (Figure 14) indicates that; 10% (3/30) of the contractors respondents worked on high rise residential building projects; 77% (23/30) of the contractors respondents worked on low rise residential building projects; 50% (15/30) of the contractors respondents worked on educational building projects; 50% (15/30) of the contractors worked on office building projects; 10% (3/30) of the contractors worked on recreational building projects and 70% (21/30) of the contractors worked on commercial building projects. 33% (10/30) of the respondents indicated that they worked on industrial building projects, dams, bus station, walkways, and prisons correctional facilities.

**Projects mainly worked on by Facility Managers**

The facilities manager (Figure 15) questionnaires indicates that; 7% (2/30) of the facility management respondents worked on high rise residential building projects; 100% (30/30) of the facility management respondents worked on low rise residential building projects; 73% (22/30) of the facility management respondents worked on educational building projects; 73% (22/30) of the facility management respondents worked on office building projects; 20% (6/30) of the facility management respondents worked on recreational building projects; 27% (8/30) of the facility management respondents worked on sports building projects and 70% (21/30) of the facility management respondents worked on commercial building projects. Only one (3%) facility management respondent indicated that industrial plants were amongst of the projects managed.

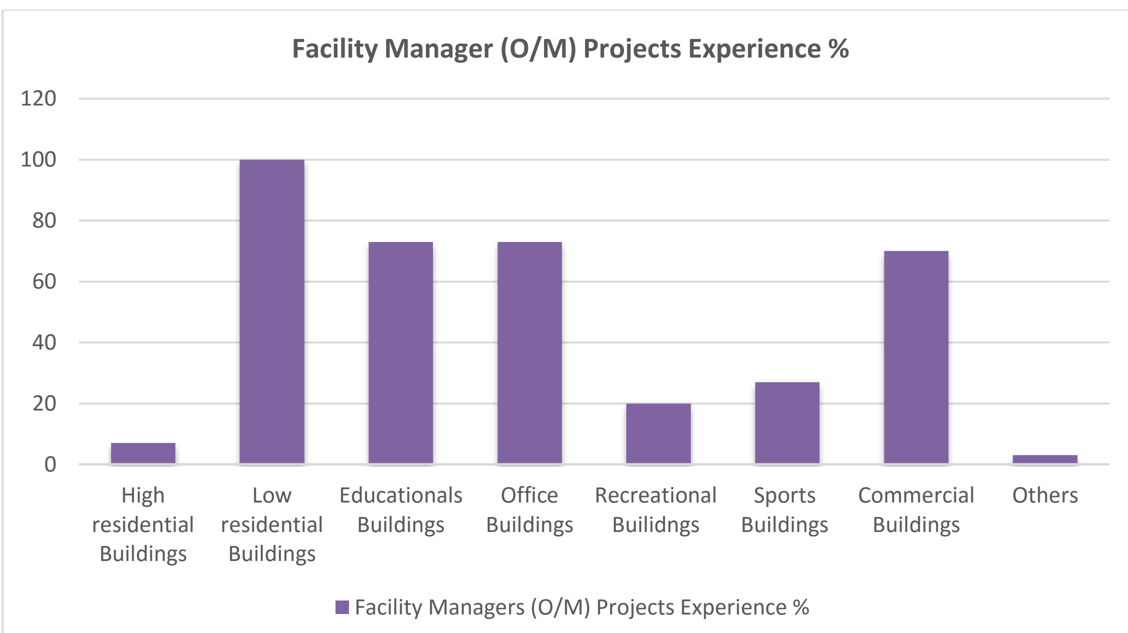


Figure 15 - Projects Executed by Facility Managers

## 5.3 CALCULATION OF IMPORTANCE INDEX FOR FACTOR ASSESSMENT

The assessment of all the thirty-six factors that affect building services coordination during design development and review stages was done with five evaluation terms: ‘Extremely Important', ‘Very Important', ‘Important', ‘Somewhat Important' and ‘Not Important'. The professional respondents to the questionnaires were asked to mark each of the factors based on the level of importance. The received responses from each of the professionals (architects, contractors and facility managers) were analyzed separately for the important index and ranking.

Three separate cases of data were analyzed using Microsoft Excel. Equation 1.3 in chapter one was used to calculate the important index. The important index results were also categorized into the levels described in chapter one classification ranges: (see Table 5,6,7).

Table 5 - Importance indexes and rate of importance of accessed factors affecting the effective coordination of building services during the design development and review stages

| Factors Affecting the Effective Coordination of Building Services during the Design Development and Review Stages | | A/E | | Contractors | | Facilities Managers | |
|---|---|---|---|---|---|---|---|
| | | Importance Index | Rate of Importance | Importance Index | Rate of Importance | Importance Index | Rate of Importance |
| **Planning Phase of the Project** | | | | | | | |
| 01. | The scale and complexity of the project. | 91 | Ext. Imp. | 76 | Very Imp. | 70 | Very Imp. |
| 02. | The schedule of the project. | 75 | Very Imp. | 61 | Important | 70 | Very Imp. |
| 03. | The allocated budget for the project. | 73 | Very Imp. | 71 | Very Imp. | 83 | Very Imp. |
| 04. | The location of the project. | 49 | Important | 43 | Important | 57 | Important |
| 05. | Availability of clear Architectural program. | 73 | Very Imp. | 71 | Very Imp. | 66 | Very Imp. |
| **Design of MEP Systems** | | | | | | | |
| 06. | The quality of the preliminary/conceptual design of the building project. | 76 | Very Imp. | 87 | Very Imp. | 70 | Very Imp. |
| 07. | The type and occupancy requirements of the building project. | 72 | Very Imp. | 60 | Important | 58 | Important |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 08. | The design complexity of the MEP systems for the building project. | 66 | Very Imp. | 72 | Very Imp. | 85 | Very Imp. |
| 09. | The process of exchanging data, information and design output among MEP systems. | 72 | Very Imp. | 73 | Very Imp. | 61 | Important |
| 10. | The aesthetic required when integrating the MEP systems into the architecture & structural systems. | 71 | Very Imp. | 65 | Very Imp. | 77 | Very Imp. |
| 11. | The cost of the specified MEP systems for the building projects. | 65 | Very Imp. | 62 | Important | 65 | Very Imp. |
| 12. | The performance of the MEP systems specified for the building project. | 68 | Very Imp. | 58 | Important | 65 | Very Imp. |
| 13. | The detailing of various components of the MEP systems. | 53 | Important | 58 | Important | 54 | Important |
| **Construction of MEP Systems** | | | | | | | |
| 14. | The material used in fabricating the MEP system specified for the building project. | 64 | Very Imp. | 61 | Important | 62 | Important |
| 15. | The required clearance for the MEP systems specified for the building project. | 60 | Important | 56 | Important | 58 | Important |
| 16. | The connection support used during installation of the MEP systems. | 63 | Very Imp. | 54 | Important | 48 | Important |
| 17. | The space allocated for the installation of the MEP systems in the building. | 78 | Very Imp. | 67 | Very Imp. | 65 | Very Imp. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 18. | The allocated time for the fabrication of the MEP systems' components. | 57 | Important | 42 | Important | 55 | Important |
| 19. | Testing requirements of the MEP systems during construction. | 53 | Important | 40 | Important | 51 | Important |
| 20. | The installation sequence of the MEP systems. | 58 | Important | 64 | Very Imp. | 48 | Important |
| 21. | Safety considerations during the installation of MEP systems. | 55 | Important | 56 | Important | 46 | Important |
| **Operation and Maintenance of MEP Systems** | | | | | | | |
| 22. | Access to the various components of the MEP systems. | 79 | Very Imp. | 66 | Very Imp. | 62 | Important |
| 23. | Safety requirements during the operation and maintenance of MEP systems. | 76 | Very Imp. | 61 | Important | 57 | Important |
| 24. | The expandability and retrofit requirements of the MEP systems' components. | 61 | Important | 63 | Very Imp. | 72 | Very Imp. |
| 25. | Availability of the spare parts required for the maintenance of MEP systems. | 69 | Very Imp. | 72 | Very Imp. | 78 | Very Imp. |
| 26. | Availability of Building management systems (BMS). | 56 | Important | 44 | Important | 46 | Important |
| **Owner** | | | | | | | |
| 27. | The clarity of the requirements & objectives provided by the owner. | 87 | Very Imp. | 80 | Very Imp. | 66 | Very Imp. |
| 28. | The type of project ownership. | 59 | Important | 57 | Important | 55 | Important |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 29. | The frequency of alterations demanded by the owner. | 71 | Very Imp. | 70 | Very Imp. | 75 | Very Imp. |
| 30. | The project delivery system adopted for the building project. | 62 | Important | 62 | Important | 49 | Important |
| 31. | Honoring agreed upon payment schedules. | 66 | Very Imp. | 61 | Important | 77 | Very Imp. |
| **Design Team and the Tools Used** | | | | | | | |
| 32. | The level of experience of the design team. | 90 | Ext. Imp. | 76 | Very Imp. | 71 | Very Imp. |
| 33 | The capacity of the firm handling the project. | 81 | Very Imp. | 66 | Very Imp. | 58 | Important |
| 34. | The comprehensiveness of the software utilized for the building design. | 66 | Very Imp. | 56 | Important | 45 | Important |
| 35 | The software literacy level of the design team. | 67 | Very Imp. | 56 | Important | 53 | Important |
| 36 | Communication skills of the design team members. | 80 | Very Imp. | 76 | Very Imp. | 71 | Very Imp. |

**Table 6 -** Importance indexes and ranks of the factors affecting the effective coordination of building services during the design development and review stages

| Factors Affecting the Effective Coordination of Building Services during the Design Development and Review Stages | | A/E | | Contractors | | Facilities Managers | |
|---|---|---|---|---|---|---|---|
| | | Importance Index | Rank | Importance Index | Rank | Importance Index | Rank |
| **Planning Phase of the Project** | | | | | | | |
| 01. | The scale and complexity of the project. | 91 | 1 | 76 | 3 | 70 | 10 |
| 02. | The schedule of the project. | 75 | 10 | 61 | 20 | 70 | 10 |
| 03. | The allocated budget for the project. | 73 | 11 | 71 | 9 | 83 | 2 |
| 04. | The location of the project. | 49 | 36 | 43 | 34 | 57 | 24 |
| 05. | Availability of clear Architectural program. | 73 | 11 | 71 | 9 | 66 | 13 |
| **Design of MEP Systems** | | | | | | | |
| 06. | The quality of the preliminary/conceptual design of the building project. | 76 | 8 | 87 | 1 | 70 | 10 |
| 07. | The type and occupancy requirements of the building project. | 72 | 13 | 60 | 24 | 58 | 21 |
| 08. | The design complexity of the MEP systems for the building project. | 66 | 20 | 72 | 7 | 85 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 09. | The process of exchanging data, information and design output among MEP systems. | 72 | 13 | 73 | 6 | 61 | 20 |
| 10. | The aesthetic required when integrating the MEP systems into the architecture & structural systems. | 71 | 15 | 65 | 15 | 77 | 4 |
| 11. | The cost of the specified MEP systems for the building projects. | 65 | 23 | 62 | 18 | 65 | 15 |
| 12. | The performance of the MEP systems specified for the building project. | 68 | 18 | 58 | 25 | 65 | 15 |
| 13. | The detailing of various components of the MEP systems. | 53 | 34 | 58 | 25 | 54 | 28 |
| **Construction of MEP Systems** | | | | | | | |
| 14. | The material used in fabricating the MEP system specified for the building project. | 64 | 24 | 61 | 20 | 62 | 18 |
| 15. | The required clearance for the MEP systems specified for the building project. | 60 | 28 | 56 | 28 | 58 | 21 |
| 16. | The connection support used during installation of the MEP systems. | 63 | 25 | 54 | 32 | 48 | 32 |
| 17. | The space allocated for the installation of the MEP systems in the building. | 78 | 7 | 67 | 12 | 65 | 15 |
| 18. | The allocated time for the fabrication of the MEP systems' components. | 57 | 31 | 42 | 35 | 55 | 26 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 19. | Testing requirements of the MEP systems during construction. | 53 | 34 | 40 | 36 | 51 | 30 |
| 20. | The installation sequence of the MEP systems. | 58 | 30 | 64 | 16 | 48 | 32 |
| 21. | Safety considerations during the installation of MEP systems. | 55 | 33 | 56 | 28 | 46 | 34 |
| **Operation and Maintenance of MEP Systems** | | | | | | | |
| 22. | Access to the various components of the MEP systems. | 79 | 6 | 66 | 13 | 62 | 18 |
| 23. | Safety requirements during the operation and maintenance of MEP systems. | 76 | 8 | 61 | 20 | 57 | 24 |
| 24. | The expandability and retrofit requirements of the MEP systems' components. | 61 | 27 | 63 | 17 | 72 | 7 |
| 25. | Availability of the spare parts required for the maintenance of MEP systems. | 69 | 17 | 72 | 7 | 78 | 3 |
| 26. | Availability of Building management systems (BMS). | 56 | 32 | 44 | 33 | 46 | 34 |
| **Owner** | | | | | | | |
| 27. | The clarity of the requirements & objectives provided by the owner. | 87 | 3 | 80 | 2 | 66 | 13 |
| 28. | The type of project ownership. | 59 | 29 | 57 | 27 | 55 | 26 |
| 29. | The frequency of alterations demanded by the owner. | 71 | 15 | 70 | 11 | 75 | 6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 30. | The project delivery system adopted for the building project. | 62 | 26 | 62 | 18 | 49 | 31 |
| 31. | Honoring agreed upon payment schedules. | 66 | 20 | 61 | 20 | 77 | 4 |
| **Design Team and the Tools Used** | | | | | | | |
| 32. | The level of experience of the design team. | 90 | 2 | 76 | 3 | 71 | 8 |
| 33 | The capacity of the firm handling the project. | 81 | 4 | 66 | 13 | 58 | 21 |
| 34. | The comprehensiveness of the software utilized for the building design. | 66 | 20 | 56 | 28 | 45 | 36 |
| 35 | The software literacy level of the design team. | 67 | 19 | 56 | 28 | 53 | 29 |
| 36 | Communication skills of the design team members. | 80 | 5 | 76 | 3 | 71 | 8 |

**Table 7** - The ranking of the combined importance index of the evaluated factors of all the professionals

| **Factors Affecting the Effective Coordination of Building Services during the Design Development and Review Stages** | | **A/E/Contractor/F.M** | |
|---|---|---|---|
| | | Average Importance Index | Rank |
| **Planning Phase of the Project** | | | |
| 01 | The scale and complexity of the project. | 79 | 1 |
| 02. | The schedule of the project. | 69 | 13 |
| 03. | The allocated budget for the project. | 76 | 5 |
| 04. | The location of the project. | 50 | 34 |
| 05. | Availability of clear Architectural program. | 70 | 11 |
| **Design of MEP Systems** | | | |
| 06. | The quality of the preliminary/conceptual design of the building project. | 78 | 3 |
| 07. | The type and occupancy requirements of the building project. | 63 | 22 |
| 08. | The design complexity of the MEP systems for the building project. | 74 | 7 |
| 09. | The process of exchanging data, information and design output among MEP systems. | 69 | 13 |
| 10. | The aesthetic required when integrating the MEP systems into the architecture & structural systems. | 71 | 10 |
| 11. | The cost of the specified MEP systems for the building projects. | 64 | 20 |
| 12. | The performance of the MEP systems specified for the building project. | 64 | 20 |
| 13. | The detailing of various components of the MEP systems. | 55 | 30 |
| **Construction of MEP Systems** | | | |
| 14. | The material used in fabricating the MEP system specified for | 62 | 23 |

| | | | |
|---|---|---|---|
| | the building project. | | |
| 15. | The required clearance for the MEP systems specified for the building project. | 58 | 25 |
| 16. | The connection support used during installation of the MEP systems. | 55 | 30 |
| 17. | The space allocated for the installation of the MEP systems in the building. | 70 | 11 |
| 18. | The allocated time for the fabrication of the MEP systems' components. | 51 | 33 |
| 19. | Testing requirements of the MEP systems during construction. | 48 | 36 |
| 20. | The installation sequence of the MEP systems. | 57 | 27 |
| 21. | Safety considerations during the installation of MEP systems. | 52 | 32 |
| **Operation and Maintenance of MEP Systems** | | | |
| 22. | Access to the various components of the MEP systems. | 69 | 13 |
| 23. | Safety requirements during the operation and maintenance of MEP systems. | 65 | 18 |
| 24. | The expandability and retrofit requirements of the MEP systems' components. | 65 | 18 |
| 25. | Availability of the spare parts required for the maintenance of MEP systems. | 73 | 8 |
| 26. | Availability of Building management systems (BMS). | 49 | 36 |
| **Owner** | | | |
| 27. | The clarity of the requirements & objectives provided by the owner. | 78 | 3 |
| 28. | The type of project ownership. | 57 | 27 |
| 29. | The frequency of alterations demanded by the owner. | 72 | 9 |
| 30. | The project delivery system adopted for the building project. | 58 | 25 |

| | | | |
|---|---|---|---|
| 31. | Honoring agreed upon payment schedules. | 68 | 16 |
| **Design Team and the Tools Used** | | | |
| 32. | The level of experience of the design team. | 79 | 1 |
| 33 | The capacity of the firm handling the project. | 68 | 16 |
| 34. | The comprehensiveness of the software utilized for the building design. | 56 | 29 |
| 35 | The software literacy level of the design team. | 59 | 24 |
| 36 | Communication skills of the design team members. | 76 | 5 |

## 5.4 FINDINGS

### 5.4.1 Assessment of the Factors by the A/E

Responses were obtained from 30 A/E located in Eastern province of Saudi Arabia. The importance indexes and the ranks for all the identified 36 factors were determined. The detailed assessment of the each of the group of factors is as follows:

***Planning phase of the project***

This group includes five factors, as shown in table 5. Respondents assessed "the scale and complexity of the project" to be extremely important, with an index value of 91%. Three factors, namely "the schedule of the project", "the allocated budget for the project", and "availability of clear architectural program" was assessed very important, with an index value of 75%, 73%, and 73% respectively. The factor "the location of the project" was assessed by the respondents to be important, with an index value of 49%. The ranks of these five factors are listed in table 6.  Among the identified factors in this category “the scale and complexity of the projects” received the highest index value. The architects strongly support the value because such factor will influence the specification and requirements for the projects and hence cause complexity during coordination.

***Design of MEP Systems***

This classification is made up of eight factors shown in Table 5. The professional respondents rate seven factors, namely “the quality of the preliminary/concept design of the building project”, “the type and occupancy requirement of the building projects”, the design complexities of the MEP systems for the building project”, “the process of exchanging data, information and design output among MEP systems” , “the aesthetic required when integrating the MEP systems into the architecture and structural systems”, “the cost of the specified MEP systems for the building projects” and “ the performance of the MEP systems specified for the building project” as “very important” with importance index values of 76%, 72%, 66%,72%, 71%, 65%, and 68% respectively. "The details of various components of the MEP systems" was valued “important” with an index value of 53%. The ranks of these eight factors are listed in Table 6. “The quality of the preliminary/conceptual design of the building projects” was evaluated with the highest value in this category. The architects agreed with this evaluation due to the relationship between architectural programs developed with client’s requirements and the quality of the conceptual drawings. Subsequent coordination will be baseless if the initial concept design is of low quality.

### *Construction of MEP Systems*

This group includes eight factors shown in Table 5. The professional respondents rate "the material used in fabricating the MEP system specified for the building projects" , the connection support used during installation of the MEP systems" and "the space allocation for the installation of the MEP systems in the building" as "very important" with an index value of 64%, 63%, and 78% respectively. "The required clearance for the MEP systems specified for the building project", "the allocated time for the fabrication of the MEP systems components", "testing requirements of the MEP systems during construction", "the installation sequence of the MEP systems components " and "safety consideration during the installation of MEP systems" was evaluated important with index value of 60%, 57%,53%,58% and 55% respectively. The ranks of eight factors are listed in Table 6. The architects agreed that "the space allocated for the installation for the MEP systems in the building" was the most important in this category. The installation spaces determine the ease of installation and installation will determine the placements of the MEP systems in the Architectural and structural systems. Any error in space allocation for installation will affect the construction of the MEP systems.

### *Operation and Maintenance of MEP Systems*

This group includes five factors shown in Table 5. The professional respondents rates "access to the various components of the MEP systems", "safety requirements during the operation and maintenance of MEP systems" and "availability of the spare parts required for the maintenance of MEP systems" as "very important" with index values of 79%, 76% and 69% respectively. "The expandability and retrofit requirements of the MEP systems components” and “availability of building management systems” was evaluated “important” with an index value of 61% and 56% respectively. The ranks of these five factors are listed in Table 6. The architects believes that "access to the various components of the MEP systems" and “safety requirements during the operation and maintenance of MEP systems” are equally important among all the factors. Without easy accessibility, the maintenance operation cannot be conducted effectively and for maintenance to be conducted on MEP systems the safety has to be guaranteed.

***Owners***

This group includes five factors shown in Table 5. The professional respondents evaluated “the clarity of the requirements and objectives provided by the owner”, “the frequency of alterations demanded by the owner” and "honoring agreed upon payments schedules" as “very important” with an index value of 87%, 71%, and 66% respectively. “The type of project ownership” and “the project delivery systems adopted for the building project” was evaluated “important” with an index value of 59% and 62% respectively. The ranks of these five factors are listed in Table 6. The architects agreed that “the clarity of the requirements and objectives provided by the owners” is the most important factor in this category because such clarity will determine the quality of Architectural program and specifications developed from the clients objectives.

***Design Team and the Tools Used***

This group includes five factors shown in Table 5. The professional respondents rate “the level of experience of the design team” as “extremely important” with an index value of

90%. “The capacity of the firm handling the project”, “the comprehensiveness of the software utilized for the building design” , “the software literacy level of the design team” and “communication skills of the design team members” was evaluated “very important” with an index value of 81%,66%,67%and 80% respectively. The ranks of these five factors are listed in Table 6. The architects agreed that “the level of experience of the design team” is the most important of all the factors because competence level of the team members affects drastically the quality of work at all phases of the building projects.

***Group evaluation by A/E***

The group evaluation was calculated as shown in Table 8. The architects ranked “design team and the tools used” as the most important category. They explained that the quality of the design team and the tools adopted will determine the progress of the coordination activities drastically.

### 5.4.2 Assessment of the Factors by the Contractors

Responses were obtained from 30 contractors located in Eastern Province of Saudi Arabia. The importance indexes and the ranks for all the identified 36 factors were determined. The detailed assessment of the each of the group of factors is as follows:

***Planning phase of the project***

This group included five factors, as presented in table 5. Contractor respondents assessed “the scale and complexity of the project”, “the allocated budget for the projects” and “availabilities of clear architectural program” to be “very important” with an index value of 76%, 71%, and 71% respectively. "The schedule of the project" and "the location of the project" was assessed as “important” with an index value of 61% and 43% respectively. The ranks of these five factors are listed in table 6. “The scale and complexity of the project" factor was evaluated with the highest important index value. The contractors presented the results disagree with the assessment, they believed that “availability of clear architectural program” should be the factor with the highest value because it affects and determine every activity that is conducted after the development of the program.

***Design of MEP Systems***

This classification is made up of eight factors shown in table 5. The Construction respondents rate “the quality of the preliminary/concept design of the building project”, “the design complexities of the MEP systems for the building project”, “the process of exchanging data, information and design output among MEP systems”, “the aesthetic required when integrating the MEP systems into the architecture” as “very important” with an index values of 87%, 72%, 73%, and 65% respectively. “The type and occupancy requirements of the building projects”, "the cost of the specified MEP systems for the Building projects”, “the performance of the MEP systems specified for the Building project” and “the details of various components of the MEP systems” was rated “important” with an index value of 58%,65%,65% and 54%. The ranks of these eight factors are listed in table 6. “The quality of the preliminary/conceptual design of the building project" was evaluated with the highest index in this category. However, the contractors disagrees with the results because "the design complexity of the MEP systems for the building project” will affect the level of effort towards coordination. The design complexity should be ranked number one instead of number three.

***Construction of MEP Systems***

This group includes eight factors shown in table 5. The professional respondents rated "the space allocated for the installation of the MEP systems in the building" and "the installation sequence of the MEP systems" as “very important” with an index value of 67%, and 64% respectively. “The material used in fabricating the MEP systems specified for the building projects”, “the required clearance for the MEP systems specified for the building projects” , “the connection support used during installation of the MEP systems”, “the allocated time for the fabrication of the MEP systems components” , “testing requirements of the MEP systems during construction” and “safety consideration during the installation of MEP systems" was evaluated “important” with index value of 61%, 56%,54%,42%,40%, and 56% respectively. The ranks of these eight factors are listed in table 6. “The space allocated for the fabrication of the MEP systems components” was evaluated with the highest important index. The contractors are in agreements because MEP spaces and installation spaces is a factor that either increase or decrease the number of clashes encountered in the project. Improper space allocation will affect MEP systems installation.

### *Operation and Maintenance of MEP Systems*

This group includes five factors shown in table 5. The contractor respondents rated "access to the various components of the MEP systems", "the expandability and retrofit requirements of the MEP systems components" and "availability of the spare parts required for the maintenance of MEP systems" as “very important” with an index values of 66%, 63% and 72% respectively. "Safety requirements during the operation and maintenance of MEP systems" and "availability of Building management systems" was evaluated “important” with an index value of 61% and 44% respectively. The ranks of these five factors are listed in table 6. “The availability of the spare parts required for the maintenance of MEP systems” was evaluated as the highest factor in this category. The contractors believed that “availability of building management systems (BMS)” should be the most important because BMS system will affect how the operation and maintenance of the MEP are conducted. The availability of BMS systems in the building will help to locate the exact point maintenance is needed and this will affect the design of all the systems.

### *Owners*

This group includes five factors as shown in table 5. The professional respondents rate “the clarity of the requirements and objectives provided by the owner” and “the frequency of alterations demanded by the owner” as “very important” with index values of 80% and 70% respectively. “The type of project ownership”, “the project delivery systems adopted for the building project” and “honoring agreed upon payments schedules” was evaluated important with an index value of 57%, 62%and 61%

respectively. The ranks of these five factors are listed in table 6. “The clarity of the requirements and objectives provided by the owner” was ranked with the highest important index value. The contractors agreed with the evaluation because client’s requirements and objectives are used for the development of project brief. An unclear clients requirements will result in repetitive work and a waste of resources.

***Design Team and the Tools Used***

This group includes five factors shown in table 5. The contractor respondents evaluated “the level of experience of the design team”, “the capacity of the firm handling the project” and “communication skills of the design team members” as “very important” with an index values of 76%, 66%, and 76% respectively. “The comprehensiveness of the software utilized for the building design” and “the software literacy level of the design team” was evaluated as “important” with an index value of 56%and 56% respectively. The ranks of these five factors are listed in table 6. “The level of experience of the design team” and “communication skills of the design team members” are the factors both ranked as the highest in this category. The contractors’ believed that both are important however the level of experience of the design team should be the most important in this category. They believe that the more experience the professionals, the higher the quality of coordination performed on the project.

***Group evaluation by Contractors***

The group evaluation was calculated as shown in Table 8. The contractors ranked “design of MEP systems” group with the highest index value. They subsequently, explained that the design is essential because it determines the level of effort and requirements necessary for effective coordination of the processes.

### 5.4.3 Assessment of the Factors by the Facility Managers

Responses were obtained from 30 facility managers located in Eastern province of Saudi Arabia. The importance indexes and the ranks for all the identified 36 factors were determined. The detailed assessment of the each of the group of factors is as follows:

***Planning phase of the project***

This group has five factors that affect design coordination, as presented in table 5. The facility manager respondents assessed “the scale and complexity of the project”, “the schedule of the project”, “the allocated budget for the project”, and “availability of clear architectural program” as “very important” with an index values of 70%, 70%, 83% and 66% respectively. The last factor “the location of the project” was assessed by the respondents as “important” with an index value of 57%. The ranks of these five factors are listed in table 6. “The allocated budget for the project” received the highest important index value. The facility managers strongly agreed with the final result. They commented that “the allocated budget for the project” is the single factor that determines direction and magnitude of the planning phase.

***Design of MEP Systems***

This classification is made up of eight factors shown in table 5. The facility managers evaluated “the quality of the preliminary/concept design of the building project”, "the design complexities of the MEP systems for the building project”, “the aesthetic required when integrating the MEP systems into the architecture and structural systems”, “the cost of the specified MEP systems for the building projects” and “the performance of the MEP systems specified for the building project" as “very important” with an index values of 70%, 85%, 77%,65%, and 65%, respectively. "The type and occupancy requirement of the building projects", "the process of exchanging data, information and design output among MEP systems" and "the details of various components of the MEP systems" was evaluated as “important” with an index value of 58%,61%, and 54%. The ranks of these eight factors are listed in table 6. The design complexity of the MEP systems for the building project has the highest important index. The facility managers accessed the final results and concluded the factor was indeed the most important. The complexity of the MEP will determine the required knowledge and expertise required to conduct the coordination, hence the more complex the systems the more the knowledge required.

### *Construction of MEP Systems*

This group includes eight factors shown in table 5. The professional respondents evaluated “the space allocation for the installation of the MEP systems in the building" as “very important” with an index value of 65%. "The material used in fabricating the MEP system specified for the building projects", "the required clearance for the MEP systems specified for the building project", "the connection support used during installation of the MEP systems”, “ the allocated time for the fabrication of the MEP systems components”, “testing requirements of the MEP systems during construction”, “the installation sequence of the MEP systems” and “safety consideration during the installation of MEP systems” was evaluated “important” with an index value of 62%, 58%,48%,55%,51%,48% and 46% respectively. The ranks of these eight factors are listed in table 6. The space allocated for the installation of the MEP systems in the building” was evaluated as the most important in this category and the facility manager strongly agreed to this value. They mentioned that the lack of proper consideration of this factors often leads to wrong placements of the MEP systems which eventually affects the occupants of the buildings.

***Operation and Maintenance of MEP Systems***

This group includes five factors shown in table 5. The professional respondents rate "the expandability and retrofit requirements of the MEP systems components" and "availability of the spare parts required for the maintenance of MEP systems" as “very important” with an index values of 72% and 78% respectively. "Access to the various components of the MEP systems", "safety requirements during the operation and maintenance of MEP systems" and "availability of Building management systems" was evaluated “important” with an index value of 62%, 57%, and 46% respectively. The ranks of these five factors are listed in table 6. “The availability of the spare parts required for the maintenance of the MEP systems” was evaluated with the highest importance index value. The facility managers agreed that the factors deserve the value because clients fundamentally cannot use the MEP systems with a damaged part that is unavailable.

### *Owners*

This group includes five factors shown in table 5. The professional respondents rate "the clarity of the requirements and objectives provided by the owner", "the frequency of alterations demanded by the owner" and "honoring agreed upon payments schedules" as “very important” with index values of 66%, 75%, and 77% respectively. "The type of project ownership" and "the project delivery systems adopted for the building project" was evaluated “important” with index values of 55% and 49% respectively. The ranks of these five factors are listed in table 6. Honoring agreed upon payment schedules was ranked with the highest important index value, but the facility managers believed that “the frequency of alterations demanded by the owner” should be the most important. They concluded that frequent change will increase the time and cost of the projects and affects the work phase’s timeline and delivery schedules.

### *Design team and the tools used*

This group includes five factors shown in table 5. The professional respondents evaluated “the level of experience of the design team” and “communication skills of the design team members" as “very important’ with importance index values of 71% and 71% respectively. "The capacity of the firm handling the project", "the comprehensiveness of the software utilized for the building design" and "the software literacy level of the design team" was evaluated “important” with an index value of 58%, 45%and 53% respectively. The ranks of these five factors are listed in table 6. “The level of experiences of the design team” and “communication skills of the design team members” was ranked with the highest important index. The facility managers after considering the final results believed that “the level of experience of the design team” should be the highest important index because team member experience affects the projects more than the communication skills. They argued that communication skills without experience amount to nothing during design coordination.

### *Group evaluation by Facility Managers*

The group evaluation was calculated as shown in Table 8.  The facility managers ranked “planning phase of the project” group with the highest index value. They also subsequently, explained that the planning phase is highest because the planning is the phase in which all other phases are performed. Unlike errors made later, any error in the planning phase will affect all aspects of the projects.

Table 8 - Importance indexes and ranks of the group's factors affecting the effective coordination of building services during the design development and review stages

| Factors Affecting the Effective Coordination of Building Services during the Design Development and Review Stages | A/E | | | Contractors | | | Facilities Managers | | |
|---|---|---|---|---|---|---|---|---|---|
| | Importance Index | Rate of Importance | Rank | Importance Index | Rate of Importance | Rank | Importance Index | Rate of Importance | Rank |
| Planning Phase of the Project. | 72 | Very Imp. | 2 | 64 | Very Imp. | 4 | 69 | Very Imp. | 1 |
| Design of MEP Systems. | 68 | Very Imp. | 4 | 67 | Very Imp. | 1 | 67 | Very Imp. | 2 |
| Construction of MEP Systems. | 61 | Important | 6 | 55 | Important | 6 | 54 | Important | 6 |
| Operation and Maintenance of MEP Systems. | 68 | Very Imp. | 4 | 61 | Important | 5 | 63 | Very Imp. | 4 |
| Owner. | 69 | Very Imp. | 3 | 66 | Very Imp. | 2 | 64 | Very Imp. | 3 |
| Design Team and the Tools Used. | 77 | Very Imp. | 1 | 66 | Very Imp. | 2 | 60 | Important | 5 |

## 5.5 IMPORTANT INDEX OF GROUP FACTORS AFFECTING COORDINATION

A group factor was calculated and analyzed to determine the importance index, rate of importance and ranking of each classification. The six group of factors results is shown in table 8.

### 5.5.1 Group Factor Analysis by Architects

The group result of the response from the architects reveals that five group factors, namely "planning phase of the projects", "design of MEP systems", "operation and maintenance of MEP systems" , "owner" and "design team and the tools used" are very important during building services coordination, with index value of 72%,68%,68%,69% and 77% respectively. "Construction of MEP systems" was termed Important with index value 61%. The ranking by the architects respondents of the group factors is listed in table 8.

### 5.5.2 Group Factor Analysis by Contractors

The group result of the response from the contractors reveals that four group factors, namely “planning phase of the projects”, “design of MEP systems”, “owner” and “design team and the tools used” are very important during building services coordination, with index value of 64%,67%,66% and 66% respectively. “Construction of MEP systems” and “operation and maintenance of MEP systems” was termed Important with index value

55% and 61%.  The ranking by the construction respondents of the group factors is listed in table 8.

### 5.5.3 Group Factor Analysis by Facility Managers

The group result of the facility managers respondents' reveal that four group factors, namely "planning phase of the projects", "design of MEP systems", "operation and maintenance of MEP systems" and "owner" are very important during building services coordination, with index value of 69%,67%,63% and 64% respectively. "Construction of MEP systems" and "design team and the tools used" was termed Important with index value 54% and 60%.  The ranking by the construction respondents of the group factors is listed in table 8.

## 5.6 TEST OF AGREEMENT BETWEEN ARCHITECTS, CONTRACTORS & FACILITY MANAGERS

The test of agreements among the respondents architects, contractors and facility managers was conducted using “The Rank-Order Coefficient of Correlation” formula (Assaf et al. 2015):

$$p = 1 - \frac{6 \sum D^2}{N(N^2 - 1)} \text{ …………………….. (1.4)}$$

Where;

$p$ = Is the rank order coefficient of correlation.

$\sum D^2$= Is the sum of the squared differences in ranks of the paired values.

N = Is the number of parameters for which the ranking in made (36 cases in this study).

The formula for $p$ includes $\frac{6 \sum D^2}{N(N^2-1)}$ term, which is subtracted from 1. The result of $p$ will determine the level of agreements between the two parties involved in the calculations. The test of agreements was conducted between the architects and contractors; the architects and facility managers; the contractors and facility managers. The results are;

- Test A: Between architects and Contractors. $p$ is computed to be 0.783268
- Test B: Between Architects and Facility Managers. $p$ is computed to be 0.559459
- Test C: Between Contractors and Facility Managers. $p$ is computed to be 0.709781

The results show that the value of $p$ is relatively high. The results reveal that there is a higher level of agreement between the architect-contractor and contractor-facility managers while the result shows there is an intermediate level of agreements between the architects and facilities managers.

## 5.7 DISCUSSION

After the completion of the questionnaire, the respondents added fifteen different factors that will affect effective building services coordination, namely;

1. Resources and staffing availability (**Group 1**).
2. Experience level of the project manager (**Group 1**).
3. Client’s seriousness (**Group 1**).
4. Leadership during coordination stages (**Group 1**).
5. Contractor selection (**Group 1**).
6. Spaces allocated for the MEP services (**Group 2**).
7. The level of client's participation in choosing MEP systems (**Group 2**).
8. Items delivery processes (**Group 3**).
9. Production of coordination services drawings (**Group 3**).
10. Labor capacity and knowledge of operation techniques (**Group 4**).
11. Client’s information management and collection of project data (**Group 5**).
12. Availability of internet based sharing and coordination method (**Group 6**).
13. Similar projects types’ the team had worked on (**Group 6**).
14. Structural adequacy to safely support the MEP loads (**Others**).
15. LEED compliance (**Others**).

The respondents rated all the factors as “extremely important”, “very important” and “important”. Among all the professionals the architects respondents perceived “the scale and complexity of the project” and “the level of experience of the design team” only as “extremely important”.  These factors were valued as “extremely important” because they increase the coordination complications. The architects respondents selected “the scale and complexity of the project”, “the level of experience of the design team”, “the clarity of the requirements and objective provided by the owner”, “the capacity of the firm handling the project” and “communication skills of the design team members” as the five most important factors affecting effective building services coordination during the design and review stage.

Contractor’s respondents evaluated the “the quality of the preliminary/conceptual design of the building project” with the highest index value among all the factors identified. The five most important factors for the contractors are “the quality of the preliminary/conceptual design of the building project”, “the clarity of the requirement and objectives provided by the owner”, “the scale and complexity of the project”, “the level of experience of the design team” and “communication skills of the design team members” (see Table 6).

Among the facility managers “the design complexities of the MEP systems for the building project” received the highest index value. This conclusion was attributed to the experiences gathered by the facility managers during the management of the building.

The facility managers respondents believed that the five most important factors affecting effective building services coordination during the design and review stage in descending order are “the design complexities of the MEP systems for the building project” , “the allocated budget for the project” , “availability of the spare parts required for the maintenance of MEP systems” and the combination of “aesthetic required when integrating the MEP systems into the architecture and Structural systems” and “honoring agreed upon payments schedules” (see Table 6).

The average overall assessments of the professionals (architects, contractors, and facility managers) is shown in Table 7. The average results reveal that the five most important factors affecting building services coordination for all the professionals are, “the scale and complexities of the project” and “level of experience of the design team” followed by “the quality of the preliminary/conceptual design of the building project and “the clarity of the requirements and objectives provided by the owner”. Lastly “allocated budget for the project”. Table 8 indicate that all the professional respondents collectively believed that the categories “planning phase of the project; design of MEP systems and owners are all “very important” for coordination while only construction of MEP systems was collectively agreed to be “important”. The agreements results indicate that during coordination exercise the architects and the contractors have a similar view of the process, an indication of an amiable work relationship. The results also reveal the amiable working relationship between the contractors and facility managers. The agreement results expose there is a less amiable working relationship between the architects and the facility managers because of the lower level of agreement, which can be attributed to different activities performed during different phases of the building.

The next chapter present the developments of the framework to increase efficiency during the process of effectively coordinating the building services during the design stage. The proposed framework will be developed based on knowledge from the literature review, professional interview and evaluated identified factors presented in this chapter.

# CHAPTER 6
# DEVELOPMENT OF THE FRAMEWORK

This chapter presents the development of the framework for the effective coordination of MEP services during the design development and review stages. Most past research are focused on the general design practices and knowledge required for MEP coordination (Zerjav et al. 2013; Korman et al. 2003; Tatum and Korman 2000). The framework aims at making the process of coordinating the Architectural, Structural and MEP services more effective and efficient. Studies on MEP management and coordination have revealed that MEP coordination affects negatively or positively the production and construction phases (Riley 2000; Wan and Kumaraswamy 2012). A building design facilitator can be created to ensure the best decisions for building services are taken during planning, controlling and coordination (Wan and Kumaraswamy 2012).

In Saudi Arabia, there exist no guidelines for activities conducted during the MEP design development and review stages. Interviews revealed that different A/E offices adopt different formal and informal approaches. This research proves the need for a standardized MEP coordination framework during the design development and review stages.

The proposed coordination framework is developed based on the knowledge obtained from international literature, observation of professional practices in Saudi Arabia and the identified factors. The framework is presented in a generic process model to ensure its adaptability to any building type. The generic framework model herein is described schematically in the form of an $IDEF_0$ (integration definition for function modeling) process model diagram. The process model displays the interaction between activities, in terms of identifying the inputs, output, controls, and mechanisms for each activity.

## 6.1 BUILDING SERVICES COORDINATION FRAMEWORK

The framework model consists of five sequential phases. Each phase is achieved through sequential activities. The five sequential processes of the framework model are (see Figure 16);

1. Develop the Project Conceptual Design.
2. Develop the Preliminary Design.
3. Prepare the Developed Design of MEP Services.
4. Prepare the Detailed Design of MEP Services.
5. Prepare the Construction Documents of MEP Services.

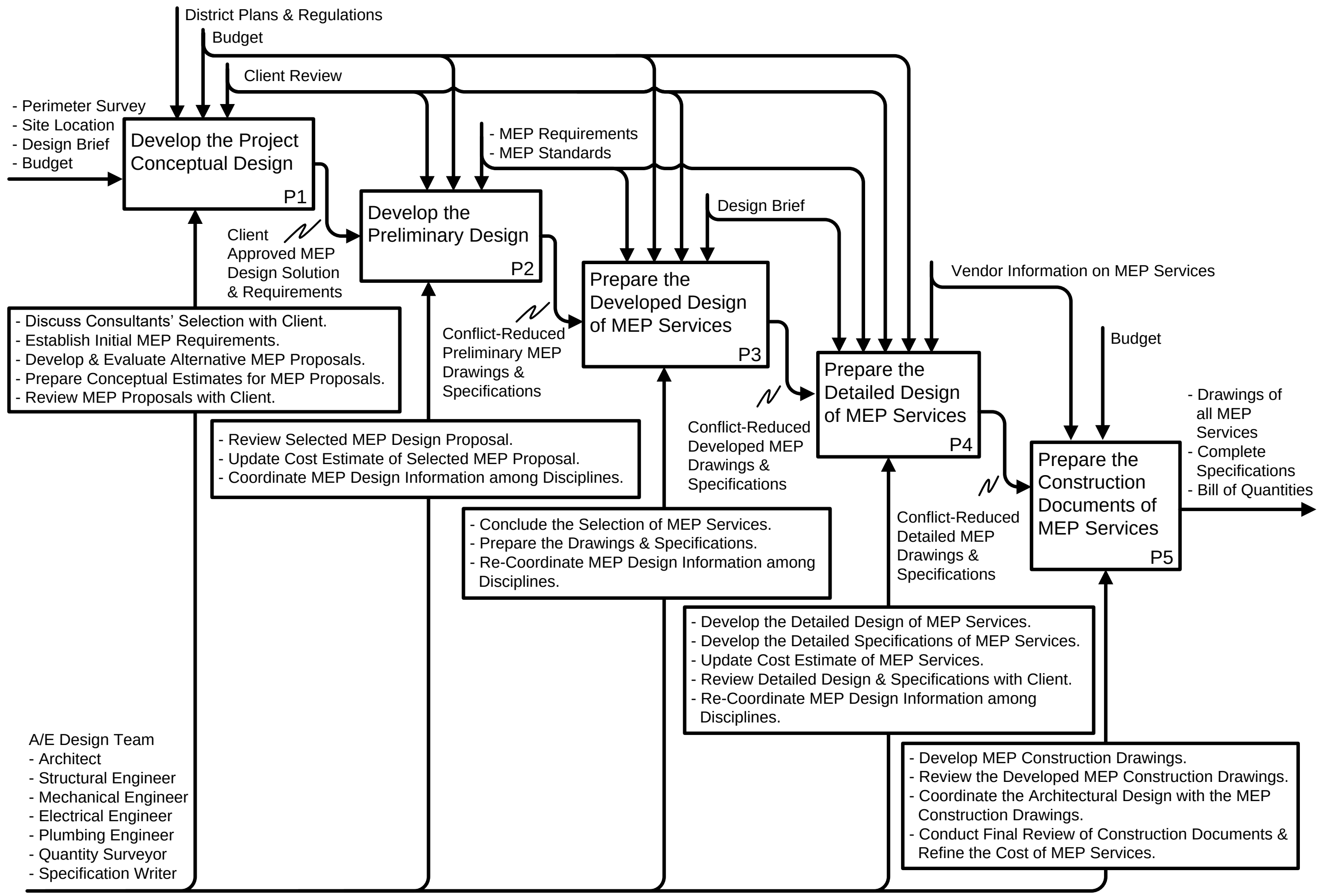


**Figure 16 -** Processes involved in MEP services coordination framework model

### 6.1.1 Develop the Project Conceptual Design

***Process Definition***

The "Develop the project conceptual design" process (node "P1" in Figure 17) involves the discussion on consultants' selection with clients, establishment of provisional MEP requirements, developments and evaluation of alternative MEP proposals, preparing conceptual estimates for MEP proposals and reviewing the MEP proposals with clients. This process entails conducting regular meetings with relevant parties, especially the client. The main inputs for this process includes the site location, perimeter survey of the plot, design brief, and project budget. These inputs facilitate the development of the site analysis according to the client needs, the requirements for MEP services, the layout of MEP systems and a conceptual cost estimate of MEP systems. The transformation of inputs to outputs within this process is controlled by the district plans and regulations, proposed project budget, MEP standards, design brief, client reviews and project schedule. The main outputs of this process are a collection of MEP requirements and approved MEP design solution by the client. This process is divided into five functions, as described and illustrated in Figure 17.

**Process Activities**

***Discuss consultants' selection with clients (P1.1):*** The selection of all professionals and consultants is the first step in this process. This step entails the selection of project team member's and discussion of the brief with the team. The definition, as well as the significant decisions concerning the project are discussed (Yu et al. 2006; Ann et al. 2007). In this task, factors such as the scale and complexity of the project, schedule of the project and the availability of a clear architectural program are taken into consideration. These factors will have a profound effect on the selection of team members and discussion with the client. Al-Shakhil (2015) indicated that usually in this early task, clients are usually more interested in the quick delivery of the project, which makes the project schedule an influential factor to consider by the design team. A well developed architectural program provides the team members with a clear goal and objectives of the project (Ryd 2004).

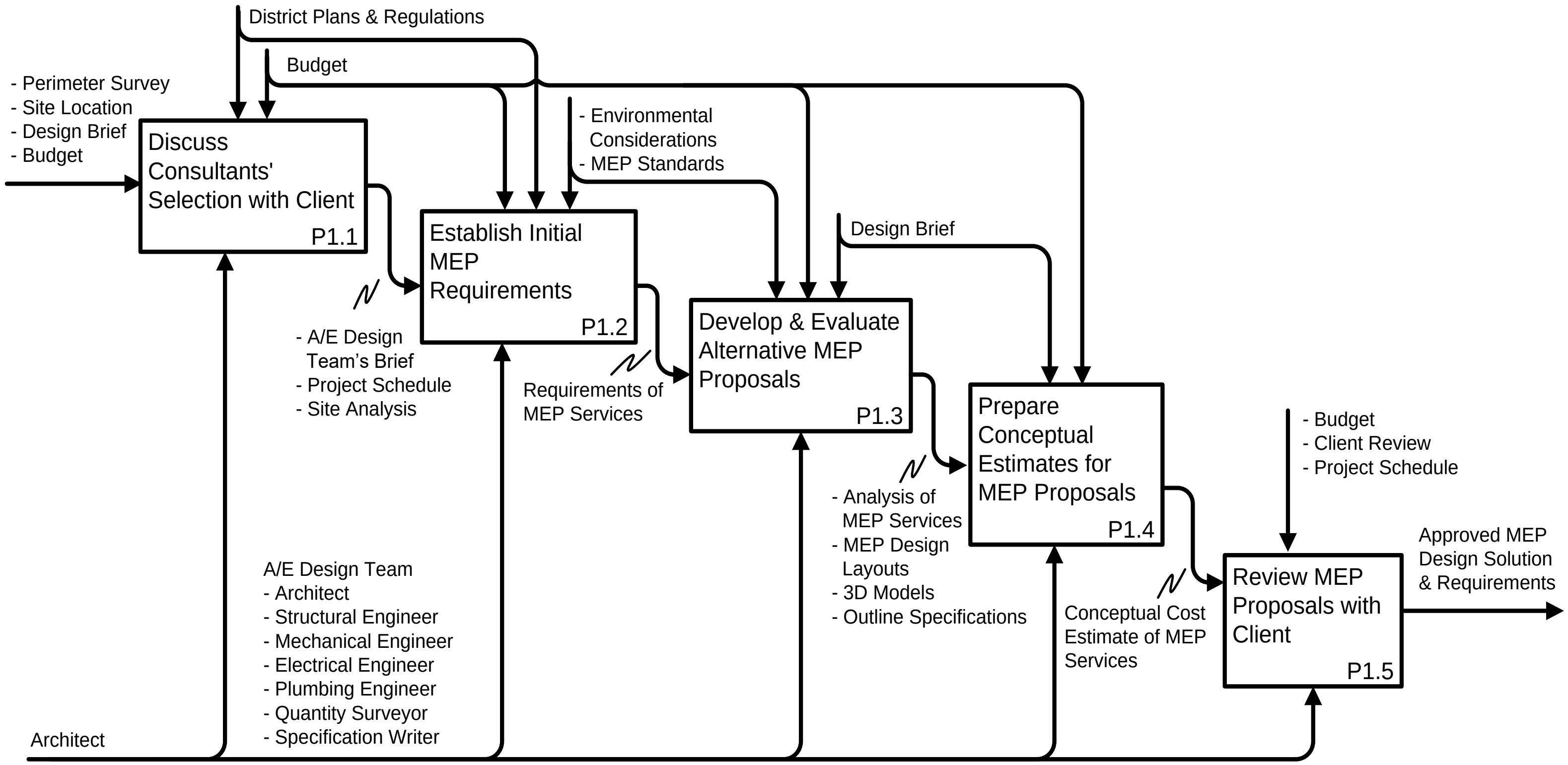


Figure 17 - Project Conceptual Design Phase

**Establish Initial MEP Requirements (P1.2):** The function serves to identify the initial MEP requirements for the project. The requirements established are the product of site analysis, client input, project brief, proposed project budget, with consideration to the delivery schedule. The overall schedule of the projects is a very important factor that affects coordination, therefore, attention is paid to the delivery schedule of the established MEP requirements (Medallah 2015). The target cost concept can be adopted to ensure that all MEP requirements are within the proposed budget (Pennanen et al. 2011).

**Develop and Evaluate Alternative MEP Proposals (P1.3):** This function entails the development of different proposals for the MEP systems. Evaluation of these different proposals is subsequently conducted and documented in a report. The input for this function are the MEP services' requirements. During the development phase, the location of the systems' components are determined, and systems' routes are established (Ashuri et al. 2014). The MEP systems' levels of complexity are also determined, due to their impacts on later coordination procedures.

**Prepare Conceptual Estimates for MEP Proposals (P1.4):** This function serves to prepare conceptual cost estimates for the MEP services' alternative proposals. Each alternative will have its unique advantages and disadvantages. The MEP services' elements and specifications determine the cost of each of the proposed alternatives (Pennanen et al. 2011). The cost of the specified MEP systems is considered to be a very important factor that affects the coordination process by the design team (Korman and

Tatum 2000; Riley 2000; Ashuri et al. 2014). Medallah (2015) and Al-Muntaser (2015) indicated that the cost estimates prepared during this step should be within plus or minus 30% of the MEP proposed budget.

**Review MEP Proposals with Client (P1.5):** This function serves to review the developed MEP proposals, reports and cost estimates with the client. This function is very significant, as it facilitate making the required decisions by the project team and the client, for the completion of the project. Inadequate reviews may result in several design changes, which will negatively affect the deliverables in subsequent phases. Such changes tend to increase the scope of work, project cost and timeline, which impacts negatively on the coordination exercise (Olawale and Sun 2015). Alterations encountered during the later stages of the design of the project can be attributed to accumulated errors during the activities of this phase (Al-Shakhil 2015; Bamardoof 2015; Medallah 2015). The clarification of all information and evaluation of all client's requirements and selection is crucial for a successful design (Shen et al. 2004).

### 6.1.2 Develop the Preliminary Design

**Process Definition**

This process (node P2 in Figure 18) involves reviewing the client's selected MEP design proposal, updating the cost estimate of the client's selected MEP proposals and coordinating all MEP design information among all design team members. This process can be achieved by ensuring that the comments and corrections made by the client on the MEP proposal are implemented. The process also involves updating the initial cost plan of the MEP systems. The information gathered are then coordinated among all the project team members. The effectiveness of this process depends largely on the experience level of the design team, the ability of the team to reflect all the corrections on the design documents. This process is constrained by the proposed budget, client's reviews, MEP requirements and standards. The inputs necessary to carry out this process are the client's approved MEP design proposal and requirements. The output from this process is a conflict-reduced preliminary MEP drawings and specifications. This process is divided into three functions as described and illustrated in Figure 18.

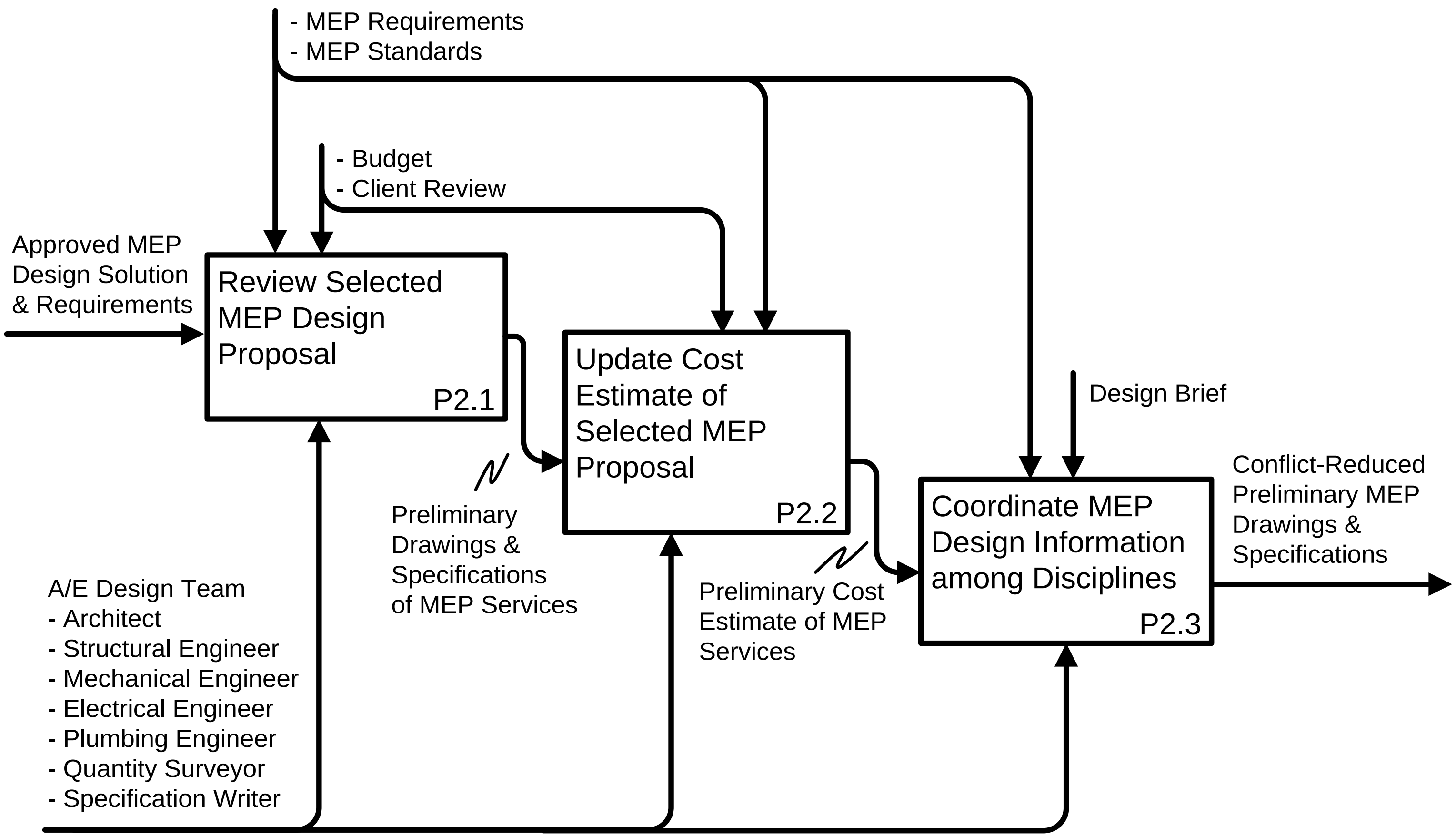


Figure 18 - Project MEP Preliminary Design Phase

**Process Activities**

**Review selected MEP design proposal (P2.1):** This function serves to ensure that the MEP proposed drawings are updated according to the client's remarks and corrections. This function serves to update the developed architectural program. Also, the more efficiently the review is performed, the less errors or mistakes that will be corrected during the design coordination activities (Boshlibi 2015). The output from this function is a preliminary set of drawings and specifications of the MEP services.

**Update cost estimate of selected MEP proposal (P2.2):** This function serves to update the initial cost estimate prepared for the selected MEP design proposal. The quantity surveyor updates the cost plan based on the revisions made to the preliminary drawings and specifications. Project cost update is required to accommodate any cost additions that may affect the project at the finishing stages (Medallah 2015). The output from this function is a preliminary cost estimate of the MEP services.

**Coordinate MEP design information among the disciplines (P2.3):** This function serves to coordinate all the information gathered among all team members to ensure that individual members are aware of the latest development on the project. The process of collecting and exchanging data and information is very important at this stage, because it affects the quality of the installed MEP systems (Chiu 2002; Odusami 2002; Ashuri et al. 2014). The output generated from this function is a set of conflict-reduced preliminary MEP drawings and specifications.

### 6.1.3 Prepare the Developed Design of MEP Services

**Process Definition**

This process (node P3 in Figure 19) involves concluding the selection of all MEP services and preparing the drawings and specifications of MEP services. The process also entails adequate re-coordination of all the developed MEP design information among the team members. In this process, all queries raised on the preliminary set of drawings and specifications are resolved. The developed design process ensures that the dimensions for the elevator shaft, overrun of the elevator and pit requirements, plant room size and other MEP systems components are reviewed, and are of the standard requirements. Design brief, schedules, and reports pertaining to MEP services are updated in the developed design stage. The input necessary for this process is the previously developed conflict-reduced preliminary set of MEP drawings and specifications. The output generated from this process is a further conflict-reduced developed MEP drawings and specifications. This process is controlled by the proposed budget, client review, design brief, MEP standards and requirements. This process is divided into three functions as described in Figure19.

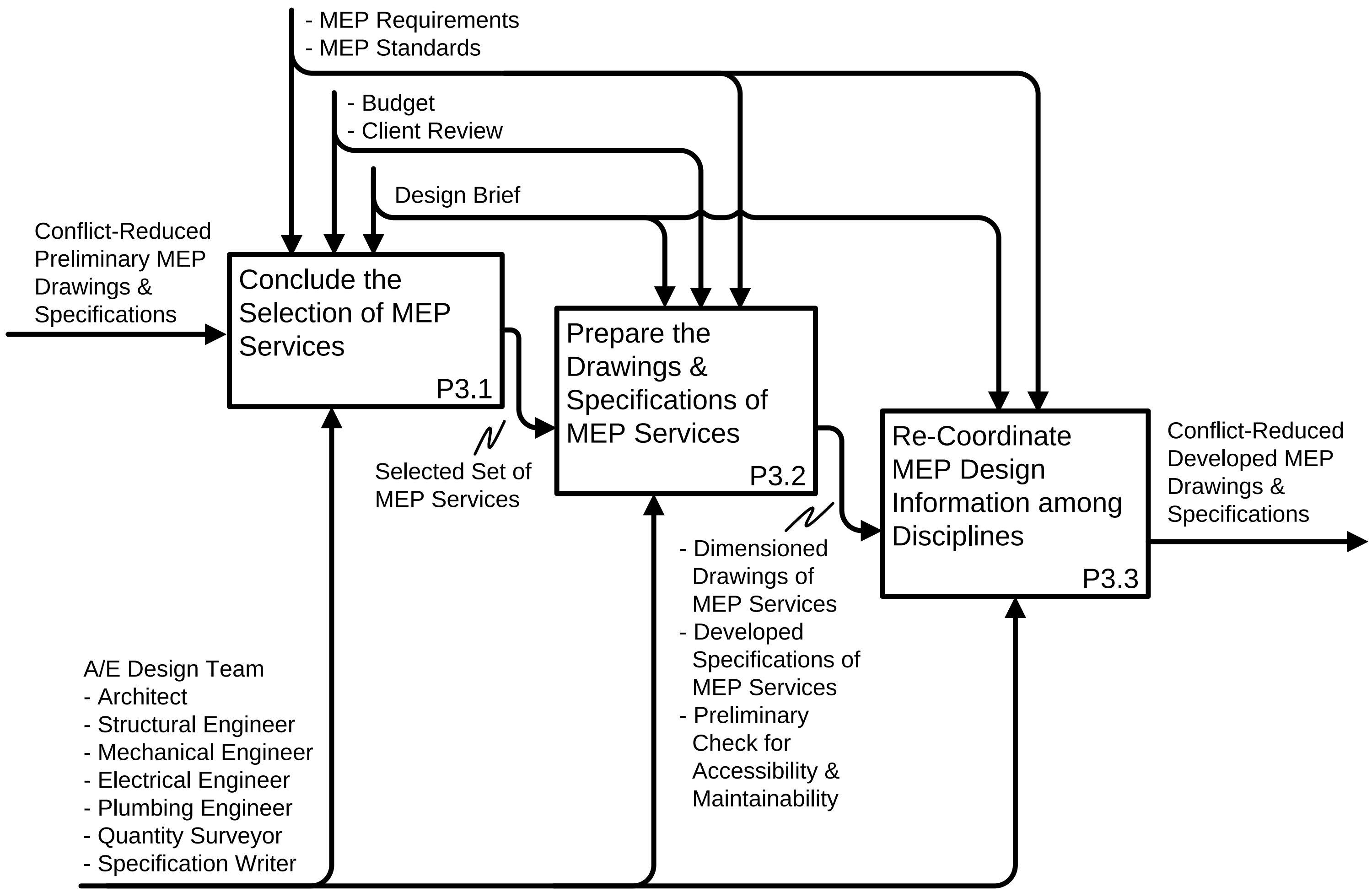


**Figure 19 -** Project MEP Developed Design Phase

**Process Activities**

**Conclude the selection of MEP services (P3.1):** This function serves to conclude on the selection of the MEP services. A clear knowledge of the design brief and client's requirements obtained during the planning, conceptual, and preliminary design stages are essential for performing this function (Yu et al. 2006). Ryd (2004) added that a clear understanding of the needs and requirements of the client will facilitate the smooth completion of this function. Through this function, the maintainability of MEP systems are checked before the final approval, and also, the availability of the spare parts for the MEP components are considered, as unavailability of spare parts may affect the downtime period of MEP services (Arditi and Nawakorawit 1999).

**Prepare the drawings and specifications of MEP services (P3.2):** This function serves to prepare the developed set of MEP drawings and specifications. The developed drawings illustrate the dimensions of all MEP services' components. The minimum dimensional clearances for all MEP services components should be adhered to when performing this function to ensure the ease of installation and organization into different spaces and levels (Leaman and Bordass 1993). Access to safety control panels and equipment are also confirmed. The maintenance personnel accessibility to different MEP components should be thoroughly evaluated to prevent hindrance during the operation and maintenance phase (Korman and Tatum 2006a). The preliminary finishes' schedules in the specifications will also be checked and updated to match the information available in the developed drawings.

**Re-coordinate MEP design information among disciplines (P3.3):** This function serves to re-coordinate all the MEP developed design information among team members to ensure that conflict arising from different drawings and specifications are resolved. The re-coordination activities require effective communication among the team members to ensure the success of the coordination processes (Chiu 2002; Medallah 2015). All the information gathered up to this stage is shared among team members. The utilization of advanced 3D model software will increase the efficiency of coordination process (Perk et al. 2014; Chiu 2002; Korman and Tatum, 2000). The final output from this function is a set of conflict-reduced developed MEP drawings and specifications.

### 6.1.4 Prepare the Detailed Design of MEP Services

**Process Definition**

This process (node P4 in figure 20), involves the detailing of all the MEP services' designs. The specifications are also detailed and the cost estimates are updated to ensure that the cost are still within the budget. This process also entails conducting periodic meetings between the design team and the client to review the detailed set of drawings and specification and discover any clashes between the systems. This process is controlled by the design brief, budget, vendor information, MEP requirements and standards. This process is very important because all the required details for the MEP services must be prepared during this phase, where clashes between the systems must be identified. The main input necessary to carry out this process is the developed MEP drawings, outline specifications from the developed stage and vendor data. The output from this process comprises of conflict-reduced, detailed MEP drawings and specifications. This process is divided into five functions as described and illustrated in Figure 20.

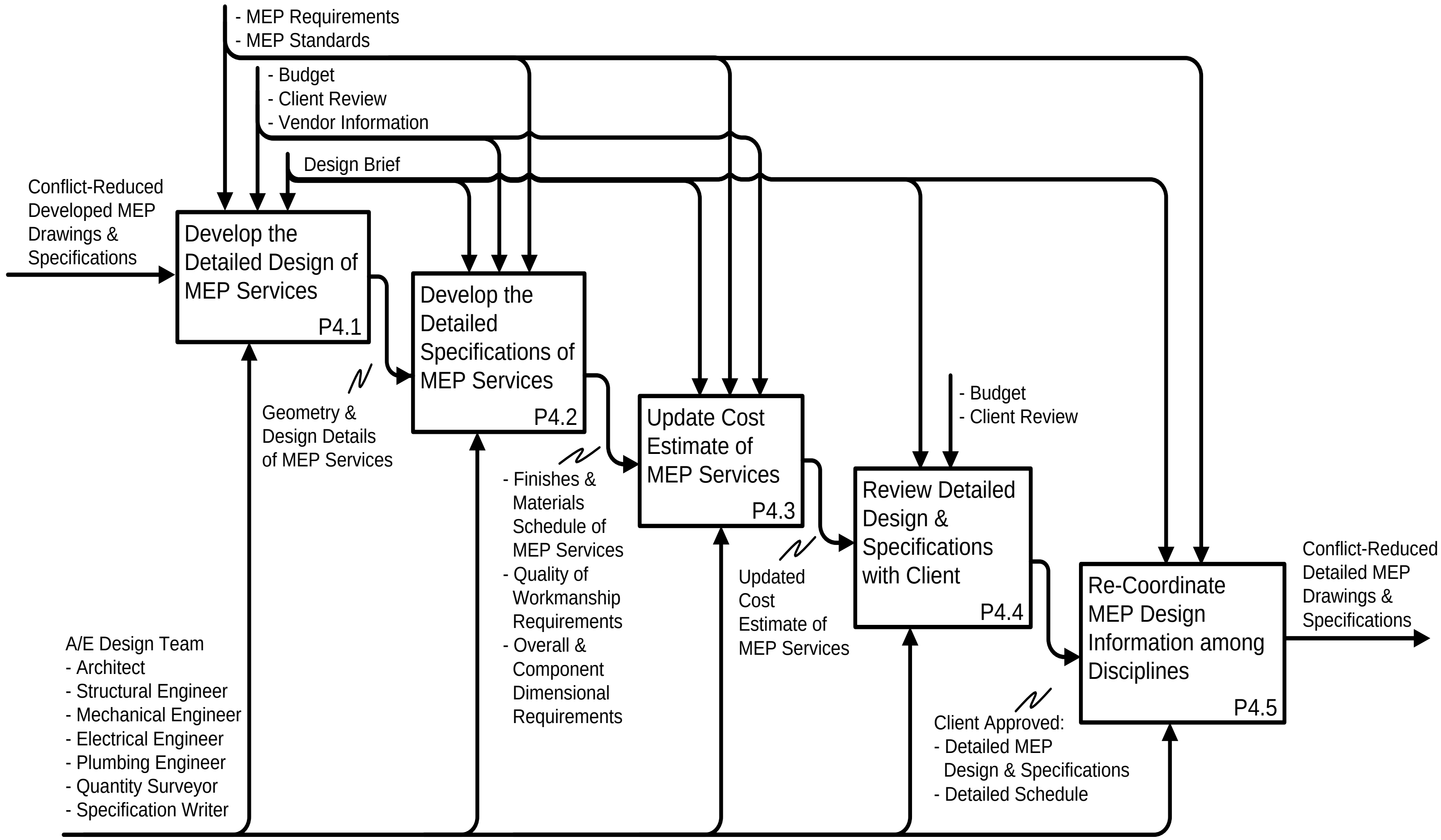


Figure 20 - Project MEP Detail Design Phase

**Process Activities**

**Develop the detailed design of MEP services (P4.1):** This function serves to prepare all the necessary MEP detailed design documents required for the project. The floor plans of all MEP services, ceiling plans reflecting lighting and services' fixtures, cross and longitudinal sections, plumbing layouts, electrical outlet and switching plans must all be adequately detailed. The detailing provided within this function illustrates the connectivity of MEP services' individual components (Korman and Tatum 2006a). This function is important, as it reveals more information to all team members on the connectivity of MEP systems (Yung et al. 2014; Korman and Tatum 2006a).

**Develop the detailed specifications of MEP services (P4.2):** This function serves to prepare all detailed specifications necessary for the installation of the MEP systems. Every detail required for the construction drawings has to be adequately described during this function. Specifications describe the routing of components through ducts and ceilings. Specifications also describe the fabrication, installation and maintenance requirements of MEP systems. The detailing provided in the specifications serves to avoid the tension when installing the MEP systems in limited spaces (Riley 2000).

**Update cost estimate of MEP services (P4.3):** This function serves to detail the developed cost estimates based on the detailed design and specifications prepared during the last step. Cost update is important due to budget constraints in projects. Clients are usually particular about how the budget is distributed among the elements of the project (Medallah 2015). Updated cost of MEP services attained during this step gives the clients a clear cost expectation for the project.

**Review detailed design & specifications with client (P4.4):** This function serves to review all the detailed design and specifications with the client. The client is usually briefed about the details, specifications and cost estimates collated during the detailed phase. Owing to the varying requirements of all MEP services, the client needs to be aware of the detailing involved. Providing the needed explanation to the client can be an enormous task for the A/E. Lack of clear explanation can lead to misunderstanding and eventually unsatisfaction of the client (Masterman and Gameson 1994).

**Re-coordinate MEP design information among disciplines (P4.5):** This function serves to coordinate all client's approved and detailed MEP drawings and specifications among the team members to resolve any conflicts that might arise from the interference of systems. The collective experiences of the team members helps in increasing the quality of coordination (Tinari 2015; Boshlibi 2015). The effectiveness of the coordination process provides for conflict-reduction during the construction phase. In situations where project team members are working from different office locations, the communication gap must be bridged through the use of frequent reviews and communication means (Hamdi 2015; Medallah 2015).

### 6.1.5 Prepare the Construction Documents of MEP Services

**Process Definition**

This process (node P5 in Figure 21), involves the preparation of all the MEP construction documents. The preparation of the construction documents is the last stage of the design process. This process ensures that all construction documents are produced to the required standards. The effectiveness of this process depends on the level of coordination between the design team to produce a conflict-free set of drawings, specifications, bill of quantities for the efficient delivery of the building project. This process is controlled by the project budget and vendor information on MEP services. The input necessary to achieve this process is a conflict-reduced and detailed MEP set of drawings and specification produced during the previous process. The final output generated from this process encompasses all developed construction drawings and specifications for MEP services, and bill of quantities. This process comprises of four different functions, as illustrated in Figure 21.

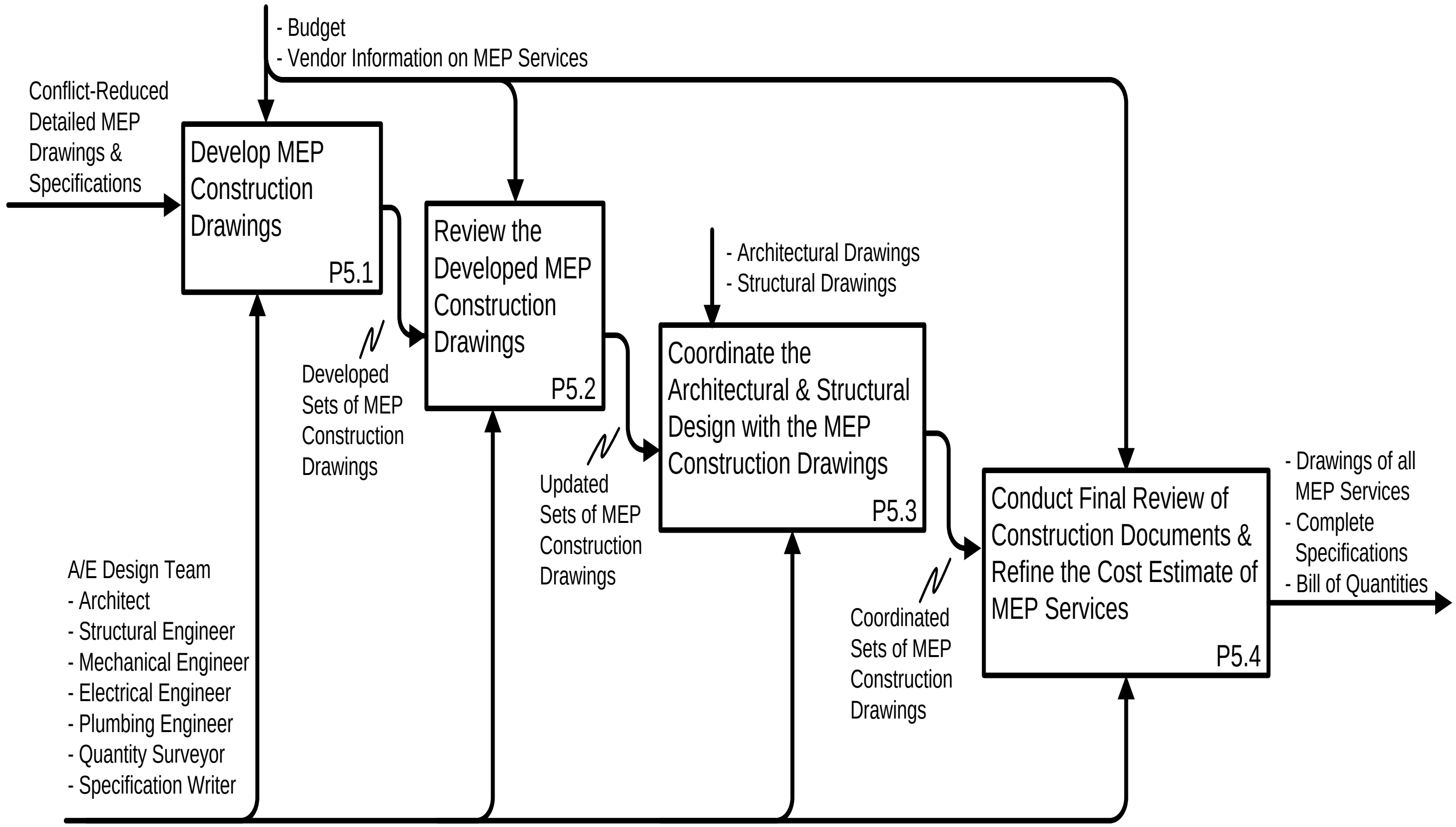


Figure 21 - Project MEP Construction Document Phase

**Process Activities**

**Develop MEP construction drawings (P5.1):** This function serves to develop all the required construction drawings for the MEP services. The construction drawings should include the fabrication and shop drawings for all MEP systems. The drawings must ensure the elimination of overlaps and duplications between disciplines, redundant, or non-applicable codes, discrepancies in the locations of equipment and components, incompatible materials and components, difficult or impossible construction methods, inconsistent terminology and abbreviations, inconsistent units of measure, incorrect or unspecified materials, components, or equipment, and inaccurate cross-referencing (CSI).

**Review the developed MEP construction drawings (P5.2):** This function serves to review all the prepared construction drawings. The review of the drawings and specifications is important for quality control. Within this function, the review of all technical specifications is also conducted (Boshlibi 2015).

**Coordinate the Architecture and Structural design with the MEP construction drawings (P5.3):** This function serves to coordinate all the MEP construction documents with the Architectural and Structural drawings of the project. Since the design of the project involves multiple team members, fragmentation is very common during the exercise (Sawhney and Maheswari 2013). Coordination at this stage aims to remove all traces of conflicts that could exist between the Architectural and/or the Structural systems and the MEP services (Riley et al, 2005).

**Conduct final review of construction documents and refine the cost estimate of MEP services (P5.4):** This function serves to conduct the final check on the construction drawings, specification schedules and total cost estimates of the MEP services. The supplementary information required during the construction processes must all be checked adequately. The final output of this function is a set of drawings of all MEP systems, complete specifications, and bill of quantities. The final review must ensure that the output is free from mistakes, discrepancies, unclear and inadequate detailing.

## 6.2 DISCUSSION

Building design coordination is still considered inefficient as indicated by several research publications around the world. In Saudi Arabia professionals interviewed stated that coordination is conducted formally or informally depending largely on the nature of the project. The professionals also mentioned that less attention is placed on coordination of residential projects (Villa) while the focus is more on big commercialized projects due to budget. Some of the problem affecting the current coordination processes were identified as lack of collaboration between professionals, lack of imaginative skills from the professional, different office location for coordination team members, client's unclear information, misinformation/interference and payment/remunerations.

This chapter presented a framework to increase the efficiency attained during design coordination. It aims at removing conflict encountered between building systems during building construction. The framework organized the activities performed during the design coordination stage and illustrated the sequence of each activity. The proposed framework was developed based on findings from the literature review and information from professionals practicing in Saudi Arabia. The framework is generic in nature making it adaptable and applicable to any project type.

The proposed framework model is explained systematically as an $IDEF_0$ process model for illustrating the MEP coordination activities in the coordination of building services during the design development and review stages. The $IDEF_0$ process model was selected after a comparison with other process models. The advantages $IDEF_0$ process model has over the others ranges from its efficiency in analyzing process flow and activities; formal methodology for the naming process, diagrams, and feedbacks; easily interpreted by professionals and flexibility. The model illustrates the relationship between input, output, control, functions and the activities. The model is a graphic illustration that reveals in details the level of functions performed in each of the nodes. The framework act as a policy guideline for conducting MEP coordination activities and reveal deliverables during the coordination activities. Representing the framework in an $IDEF_0$ format helps the building design team members to know, what function to perform, what is necessary to execute individual function, constraints of functions and what is necessary to achieve the function.

**Advantages of the developed framework are the following;**

- Presents building design team members with descriptions of standardized MEP coordination functions that need to be performed, data necessary to perform the functions and constraints controlling the function;

- The required activities to be performed by the building design team members in every process phase.
- The building design team members will identify with ease all required activities in the processes due to the graphical illustration.
- The framework can be adapted for the coordination of different project types.

The next chapter present the validation of the developed framework. The validation will be conducted through a structured interview with selected group of professionals responsible for Building services coordination in their various firms.

# CHAPTER 7

# VALIDATION OF THE DEVELOPED FRAMEWORK

The framework was designed based on the information from the literature review, observed professional practice and current practices in Saudi Arabia gathered through interviews. The assessment was conducted to ascertain the significance and applicability of the developed framework in Saudi Arabia.

The framework was assessed through a structured interview with ten A\E professionals practicing in Eastern province of Saudi Arabia. A questionnaire survey was developed and administered.

## 7.1 DEVELOPMENT OF THE QUESTIONNAIRE SURVEY

A questionnaire survey was developed based on the activities performed during each of the five phases of design coordination. The questionnaire survey was presented during the interviews with the professionals and the framework diagrams were also used for demonstration and explanation of the processes involved in the framework.

The developed questionnaire survey consisted of two parts;

- Part one: This part contains the general questions about the respondent's area of professional practice and experience.
- Part two: This part focuses on the assessment of the processes involved in the developed framework.

### 7.1.1 Pilot Testing of the Questionnaire Survey

A pilot testing of the developed questionnaire was conducted among a selected sample of five Architects/Job captains in the Eastern province of Saudi Arabia for the purpose of;

- Confirming the occurrence of the activities presented in the framework.
- Identifying any ambiguities in the survey.
- Incorporating additional activities, if required.
- Reviewing the clarity of each activity in the framework.

The initial number of activities in the framework developed was twenty four, after the pilot testing the number of activities was reduced to twenty.

## 7.2 DISTRIBUTION OF THE TESTED QUESTIONNAIRE SURVEY

The questionnaire and the framework diagrams were demonstrated and explained to ten selected Architects/Job captains in Eastern province physically. The respondents to the questionnaires were asked to indicate their perceived relative degree of importance for each of the identified activities through the selection of one of five evaluation terms; "Extremely Important" , "Very Important" , "Important" , "Somewhat Important" and "Not Important". The respondents were also asked to indicate whether their firms perform the identified activities by selecting (Yes) or (No).

## 7.3 DATA ANALYSIS

Data obtained from the interviews with the ten A\E professionals are categorized into two parts;

- Part one: General information about the respondents.
- Part two: Assessment of activities pertaining to the coordination process during the project design phases.

## 7.4 GENERAL INFORMATION

This part aims at identifying the years of experience, the position of the respondents in their organizations and the types of the projects coordinated.

**Respondents' years of experience**

The years of experience were classified into four main categories: 'Less than 5 years', '5-10 years', '10-20 years' and 'Over 20 years'. The results show that 20% of the respondents have experience ranging between 5-10 years, and 20% of the respondents have over 20 years' experience, while 60% have experience between 10-20 years.

**Respondents position in their organizations**

Interviews were conducted with ten design coordinators. The design coordinators are responsible for the coordination of the building design and services during the design development and review stages.

**Project coordinated by respondents**

This section is meant for the respondents' to indicate the types of projects they had worked on during their years of experience. The results reveal that all the ten respondents (100%) had worked on residential low rise, office and commercial building projects. Nine of the respondents (90%) had worked on educational building projects; eight of the respondents (80%) had worked on recreational building projects; seven of the respondents (70%) had worked on residential high-rise building projects; five of the respondents (50%) had worked on sports building projects and three (30%) indicated they had individually worked on substations, healthcare, and laboratory projects.

## 7.5 ASSESSMENT OF ACTIVITIES IN THE COORDINATION PROCESS DURING THE PROJECT DESIGN PHASES

The respondents' assessments of the steps of the framework were analyzed and the importance indexes were calculated using the equation 1.3 in chapter one. The rates of importance were determined according to the range specified in chapter one. Table 9 shows the activities, the important indexes, the rate of importance and question about performing the activities in respondents various offices.

Table 9 - Importance index and the rate of importance.

| Steps of the framework for the effective coordination of MEP services during the design development and review stages | | Level of Importance | | Do you perform this function in your firm? | |
|---|---|---|---|---|---|
| **Project Conceptual Design Phase** | | **Importance Index** | **Rate of Importance** | **Yes** | **No** |
| 1. | Project consultants' selection with the client. | 90 | Ext. Imp. | 100% | - |
| 2. | Preparation of initial MEP requirements for the project. | 80 | Very Imp. | 100% | - |
| 3. | Development and evaluation of alternative MEP proposals. | 70 | Very Imp. | 70% | 30% |
| 4. | Preparation of conceptual cost estimates for the MEP proposals. | 85 | Very Imp. | 90% | 10% |
| 5 | Review of MEP proposals with the client. | 78 | Very Imp. | 100% | - |
| **Project MEP Preliminary Design Phase** | | | | | |
| 1. | Review of client selected MEP design proposal. | 55 | Important | 40% | 60% |
| 2. | Updating of the cost estimate of the selected MEP proposal. | 68 | Very Imp. | 40% | 60% |
| 3. | Coordination of MEP design information among the design team members. | 65 | Very Imp. | 60% | 40% |
| **Project MEP Developed Design Phase** | | | | | |
| 1. | Conclusion of the selection of MEP services for the project | 65 | Very Imp. | 60% | 40% |
| 2. | Preparation of drawings and specifications for the MEP services | 63 | Very Imp. | 70% | 30% |
| 3. | Re-coordination of all MEP design information among the design team members. | 70 | Very Imp. | 80% | 20% |

| | | | | | |
|---|---|---|---|---|---|
| **Project MEP Detail Design Phase** | | | | | |
| 1. | Development of all detailed designs for the MEP services. | 70 | Very Imp. | 90% | 10% |
| 2. | Developments of all the detailed specifications for the MEP services. | 70 | Very Imp. | 90% | 10% |
| 3. | Updating of the cost estimate of the MEP services. | 83 | Very Imp. | 90% | 10% |
| 4. | Review of the detailed design and specifications with the client. | 70 | Very Imp. | 90% | 10% |
| 5. | Re-Coordination of all MEP design information among the design team members. | 83 | Very Imp. | 100% | - |
| **Project MEP Construction Document Phase** | | | | | |
| 1. | Development of all MEP construction drawings. | 80 | Very Imp. | 100% | - |
| 2. | Review of all prepared MEP construction drawings. | 68 | Very Imp. | 100% | - |
| 3. | Coordination of the Architectural/Structural design with all MEP construction drawings. | 90 | Ext. Imp. | 100% | - |
| 4. | Final review of the construction documents and refinement the cost estimate for all MEP services. | 88 | Ext. Imp. | 100% | - |

### 7.5.1 Project conceptual phase

The average evaluation of the five activities in the project conceptual phase was "Very Important". The calculated average importance index was 81 and table 9 shows how the respondents evaluated the activities of the project conceptual phase. The results reveal that the respondents viewed "Project consultant selection with the clients" as "Extremely Important", and the remaining activities in the conceptual phase as "Very Important". When asked if their firm performs the activities, 100% of the respondents indicated that they are exercising “Project consultants’ selection with the clients”, “Preparing of initial MEP requirements for the project” and “Reviewing of MEP proposals with the client”. 90% of the respondents reveal that they are exercising “Preparation of conceptual cost estimates for the MEP proposals”. 70% of the respondents reveal that they exercise “Development and evaluation of alternatives MEP proposals”. 30% of the respondents indicated that they do not exercise “Development and evaluation of alternatives MEP proposals”. 10% of the respondents also indicated that they do not exercise “Preparation of conceptual cost estimates for the MEP proposals”.

### 7.5.2 Project MEP preliminary design phase

The average evaluation of the three activities in the project MEP preliminary design phase was “Very Important”. The calculated average importance index was 63 and table 9 shows how the respondents evaluated the activities of the project MEP preliminary design phase. The results reveal that the respondents believed that “Updating of the cost estimates of the selected MEP proposal” and “Coordinating of MEP design information among the design team members” is “Very Important” while the respondents believed “Reviewing of clients selected MEP design proposal” is “Important”. When asked if their firm perform the activities, 60% of the respondents indicated that they exercise

“Coordinating of MEP design information among the design team members”. 40% of the respondents indicated that they do conduct “Reviews of clients selected MEP design proposal”. 40% of the respondents also indicated that they perform “Updating of the cost estimates of the selected MEP proposal”. 60% of the respondents indicated that they do not exercise “Reviewing of clients selected MEP design proposal” and “Updating of the cost estimates of the selected MEP proposal”. 40% of the respondents indicated that they do not conduct “Coordinating of MEP design information among the design team members”.

### 7.5.3 Project MEP developed design phase

The average evaluation of the three activities in the project MEP developed design phase was “Very Important”. The calculated average importance index was 66 and table 9 shows how the respondents evaluated all the activities in the “Project MEP developed design phase” as ‘Very Important”. When asked if their firm perform the activities, 80% of the respondents indicated that they are exercising “Re-coordination of all MEP design information among the design team members”. 70% of the respondents indicated that they perform “Preparation of drawings and specifications for the MEP services” while 60% of the respondents indicated that they perform “Conclusion of the selection of MEP services for the Project”. 40% of the respondents indicated that they do not exercise the “Concluding of the selection of MEP services for the Project”. 30% of the respondents indicated that they do not exercise the “preparation of drawings and specifications for the

MEP services”. 20% of the respondents indicated that they do not exercise the “Re-coordination of all MEP design information among the design team members”.

### 7.5.4 Project MEP detail design phase

The average evaluation of the five activities in the project MEP detail design phase was “Very Important”. The calculated average importance index was 75 and table 9 shows how the respondents evaluated all the activities in the “Project MEP detail design phase" as ‘Very Important". When asked if their firm performs the steps, 100% of the respondents indicated that they do exercise "Re-coordination of all MEP design information among the design team members”. 90% of the respondents indicated that they do perform the “Development of all detailed designs for the MEP services”, “Developments of all the detailed specifications for the MEP services”, “Updating of the cost estimates of the MEP services” and “Review of the detailed design and specifications with the client”. 10% of the respondents indicated that they do not perform the “Development of all detailed designs for the MEP services”, “Developments of all the detailed specifications for the MEP services”, “Updating of the cost estimates of the MEP services” and “Review of the detailed design and specifications with the client”.

### 7.5.5 Project MEP construction documents phase

The average evaluation of the four activities in the project MEP construction document phase was “Very Important”. The calculated average importance index was 82 and table

9 shows how the respondents evaluated all the activities in the “Project MEP construction document phase”. The respondents evaluated “Coordination of the Architectural/Structural design with all MEP construction drawings” and “Final review of the construction documents and refinement the cost estimate for all MEP services” as “Extremely Important”. The “Development of all MEP construction drawings” and “Review of all prepared MEP construction drawings” was evaluated as “Very Important”. 100% of the respondents indicated that they exercise all the activities in the phase.

## 7.6 DISCUSSION

The Average evaluation of all the framework phases was “Very Important” by the respondents. The calculated average importance index was 73, however the “Project MEP preliminary design phase” and “Project MEP developed design phase had the lowest score among the five phases. This two phases also had the lowest level of evaluation. When asked if their firm performs the steps, during the face-to-face discussion about the framework, 80% of the respondents indicated that in the coordination of small projects such as villas, the activities in phase two and three are combined as one phase for cost and time reduction purposes. Overall, the respondents ranked “Project consultants selection with the clients”, “Coordination of Architectural/Structural design with all MEP construction drawings” and “Final review of the construction documents and refinements of the cost estimates for all MEP services” as “Extremely Important” activities in the framework. The next chapter present the thesis conclusions and recommendations.

# CHAPTER 8
# CONCLUSIONS AND RECOMMENDATIONS

In this research, thirty-six factors affecting the process of effective coordination of building services during the design development and review stages were identified and assessed by architectural/ engineering professionals, contractors and facility managers in Eastern province of Saudi Arabia. The knowledge gained from the literature review and the assessment of the thirty-six was used to develop a generic framework for effective building services coordination during the design stage. Subsequently, the framework was assessed to ascertain its applicability by design coordinators practicing in the Eastern province of Saudi Arabia. This chapter presents a summary of the research, the conclusions, and recommendations for future research studies.

## 8.1 SUMMARY OF THE STUDY

The main objectives of this research are to identify and access the factors that influence the process of effective coordination of building services during the design development and review stages from the perspective of the design professionals, contractors, and facility managers; to develop a framework for the process of effective coordination of building services during the design development and review stages; to validate the developed framework through conducting interviews with ten design professionals in ten consulting office in Eastern province of Saudi Arabia. The research methodology consists of six different phases;

**Phase 1:** This phase focused mainly on investigation and identification of the local and international processes of building coordination. The international process of building services coordination was determined through detailed literature reviews while the local processes were determined through interviews. The interviews was conducted among ten Architects working in different A/E design firms in Eastern province of Saudi Arabia. The interviews resulted in understanding the scope of practices; the process of building design/MEP services coordination; significance of the coordination process; issues affecting effective coordination; consequences of ineffective coordination; means of receiving feedback and means of improving the coordination processes.

**Phase 2:** This phase identified and assessed the thirty-six factors influencing the effective coordination of Building services. The thirty-six factors were identified through the interviews conducted, literature review and pilot testing of the list. The factors identified were categorized into six different groups namely; factors related to the planning phase of the project; factors related to the design of MEP systems; factors related to the construction of MEP systems; factors related to the operation and maintenance of MEP systems; factors related to the owners and factors related to the design teams and tools utilized. The questionnaire survey was developed and distributed to the calculated sample size of A/E. contractors and facility management office in Eastern province of Saudi Arabia.

**Phase 3:** This phase focused on the data analysis and the results of the evaluated questionnaire survey from the A/E, contractor, and facility management professionals.

After the pilot testing, thirty surveys was received from each respondent group, summing up to a total of ninety respondents. The first section of the data analysis focuses on the years of experience and project experience of the respondents. The second section focuses on the calculation of the importance indexes, the rate of importance and ranking of the factors for the individual professional group. A combined importance indexes and ranking for all the professional respondents was also presented, followed by a group factor importance indexes and ranking for the professionals separately. The last part of this phase was dedicated to the calculation of test of agreement between architects, contractors and facility managers.

**Phase 4:** This phase focused on the development of a generic framework and the explanation of all the activities required in each of the phases. The framework was structured into five sequential processes namely; development of the project conceptual design, development of the preliminary design, preparing of the developed design of the MEP services, preparing of the detailed design of the MEP services and preparing the construction documents of the MEP services. Each phase of the framework was further subdivided into several activities to execute the phases. Each phase was also described with its input, output, and constraints.

**Phase 5:** This phase focused on the validation of the developed generic framework by a selected number of architects/Job captains in Eastern province of Saudi Arabia. The assessment revealed how the professionals practicing viewed all the activities in the developed framework.

**Phase 6:** This phase focused on the conclusions and recommendations of the thesis. Also, area of future research studies was emphasized.

## 8.2 CONCLUSIONS

The findings of this study is explained according to the research objectives listed in section 1.3 as follows;

**OBJECTIVE 1;**

To identify and assess the factors that affect the process of effective coordination of building services during the design development and review stages from the perspective of design professionals, contractors, and facility managers. The identified factors was presented in chapter 4 and discussed in section 4.1. The assessments of the factors was presented in section 5.1. The questionnaire used is presented in appendix 2 and the following are the list of conclusions drawn;

1. Thirty-six factors that affect the processes of effective coordination were identified through literature reviews, professional interviews, and the pilot study. All the identified factors were grouped into six categories namely; factors related to the planning phase of the project; factors related to the design of MEP systems; factors related to construction of MEP systems; factors related to the operation and maintenance of MEP systems; factors related to the owners and factors related to the design team and tools used.

2. The assessments of the thirty-six identified factors were conducted by thirty architects, thirty contractors and thirty facility managers in Eastern province to determine the importance index, the rate of importance and rank of importance of all the identified factors.
3. The results revealed that most (90%) of the architects worked on low-rise residential and commercial projects. Most (77%) of the contractors worked on low-rise residential building projects and all (100) the facility managers responded they had worked on low-cost residential projects.
4. The respondents evaluated all the identified factors. All the factors were assessed as "extremely important", "very important" or "important". Only "the scale and complexity of the project" and "the level of experience of the design team" was assessed to be "extremely important" by the architects. The contractors ranked "the quality of the preliminary/conceptual design of the building projects" as the most important factor among all thirty-six factors. The facility managers ranked "the design complexity of the MEP systems for the building projects" as the most important factor among the thirty-six factors. Collectively all the professionals ranked "the scale and complexity of the project" as the number one most important factor out of all the identified thirty-six factors.
5. After the completion of the questionnaire, the respondents added fifteen other factors that affect building services coordination, namely;

   **Group 1** - Resources and staffing availability; experience level of the project manager; client's seriousness; leadership during coordination stages; contractor selection.

**Group 2** - Spaces allocated for the MEP services; level of client's participation in choosing MEP systems.

**Group 3** -Items delivery processes; production of coordination services drawings.

**Group 4** - Labor capacity and knowledge of operation techniques.

**Group 5** - Client's information management and collection of project data.

**Group 6** - Availability of internet based sharing and coordination method; similar projects types' the team had worked on.

**Others** - Structural adequacy to safely support the MEP loads; LEED compliance.

6. Among the six categories of the factors, architects ranked "design team and the tools" group as the number one most important group that affects coordination. The contractors ranked the "design of MEP systems" as number one most important group while the facility managers ranked "planning phase of the projects" group as the number one most important group.
7. The results of the distributed survey was tested for the levels of agreement between the three categories of respondents namely; architects, contractors and facility managers. The level of agreements between the architects and contractors ($p$= 0.783268) and contractor and facility managers ($p$=0.709781) was at a high level while architects and facility managers ($p$= 0.559459) was intermediate. The agreements level indicate that the architects and the contractors share similar perspective towards the building project. Also, the contractors and the facility managers view the project similarly. The architects and the facility managers, had a reduced agreement level signifying the two professionals view the building projects slightly differently.

**OBJECTIVE 2;**

To develop a framework for the process of effective coordination of building services during the design development and review stages. The framework thus developed was presented in figure 16 and discussed in section 6.1.1 to 6.1.5. The details of each phase of the framework were presented in figure 16 to 21. The following is a list of conclusion drawn;

1. The framework was developed based on all the information gathered. The initial list of activities for the framework was twenty-four and the activities were discussed with five project coordinators, subsequently, it was reduced to twenty steps.
2. The twenty activities was divided into five projects phases. The phases are, develop the project conceptual phase; develop the preliminary design ; prepare the developed design of MEP services ; prepare the detailed design of MEP services and prepare the construction documents for MEP services. It was designed in a generic pattern, to ensure it can be adapted and applied to any building projects.

**OBJECTIVE 3;**

To validate the developed framework through conducting interviews with ten consulting offices in Eastern province of Saudi Arabia. The framework was validated through development, testing and administering of questionnaire survey and interview. The processes of validation was presented in chapter 7 and discussed in 7.5. The questionnaire used was presented in appendix 3 and the following are the list of conclusions drawn;

1. Validation of the framework was initiated to determine its practical applicability. The developed framework was assessed by ten architects/design coordinators.
2. The description of the proposed framework phases are;
    - Project conceptual design phase: establishments of the MEP requirements and developments of alternative MEP design proposals.
    - Project MEP preliminary design phase: reviewing of clients selected MEP design proposals, cost, and brief.
    - Project MEP developed design phase: conclusion of selected MEP services and preparation of drawings and specifications.
    - Project MEP detail design phase: developments of the detailed MEP services design, specifications and detail clients review.
    - Project MEP construction document phase: development of all necessary MEP construction documents and final coordination with architectural and structural designs.
3. The framework assessment by the Architects revealed that the phases and activities was either evaluated as "extremely important" or "very important" or "important". The project conceptual design phase, project MEP detail design phase and project MEP construction document phase was assessed as the most important among the five design phase, irrespective of the scale and

complexities of the MEP systems of the project. The flexibility of the framework was affirmed and consider applicable.

## 8.3 RECOMMENDATIONS

The following recommendations was established from the thesis;

1. The factors identified are important for both research and professional practice.
2. Companies should consider the importance of having a guide or framework for building services coordination during the design development and review stages.
3. The building services coordination framework model provides information, required guidance, and direction for design team members.
4. The efficiency level of building services coordination will be increased if the proposed framework is adopted.
5. The proposed framework can be used flexibly for small and large scale projects by local practitioners (A/E).

## 8.4 DIRECTION FOR FURTHER RESEARCH

Coordination is an activity that is important during building project delivery. Building services coordination has become an important focus for international research. This is because increased efficiency in the coordination process will reduce error and rework drastically. Future research may be considered in the following areas;

- The area relating to building services coordination during the construction phase to increase efficiency in the building delivery.
- Future studies can focus on the effective coordination during the building services procurements phases.
- Research can focus on effective building services coordination during the building services pre-construction phases.
- Future studies may also focus on effective coordination of building services during the operational and maintenance phase of the building projects.

# REFERENCES


Akbiyikli, R., & Eaton, D. (2012). Design and Design Management in Building Projects: A Review. *E-Journal of New World Sciences Academy,7(1), 1A0304.*

Al-Muntaser, T. (2015), Interview, Revit Department Head at Radicon Assystem,Al-Khobar, Eastern Province, Saudi Arabia, October 25.

Al-Shakhil, M. A. (2015), Interview, Director at AMS Architects & Engineers, Saihat, Eastern Province, Saudi Arabia, October 13.

Ambrose, J. E. (1992). *Building Construction - service systems*.Van Nostrand Reinhold, New York.

Ammeter, A. P., & Dukerich, J. M. (2002). Leadership, team building, and team member characteristics in high performance project teams. *Engineering Management Journal, 14(4), 3-10.*

Ann, T. W., Shen, Q., Kelly, J., & Hunter, K. (2007). An empirical study of the variables affecting construction project briefing/architectural programming. *International Journal of Project Management, 25(2), 198-212.*

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K. (2011). BIM adoption and implementation for architectural practices.*Structural Survey, 29(1), 7-25.*

Arditi, D., & Nawakorawit, M. (1999). Designing buildings for maintenance: designers' perspective. *Journal of Architectural Engineering, 5(4), 107-116.*

Ashuri, B,. Yarmohammadi, S., & Shahandashti, M. (2014). A critical review of methods used to determine productivity of mechanical,electrical, and plumbing systems coordination. *Construction Research Congress, 777-786.*

Assaf, S. A., & Al-Hejji, S. (2006). Causes of delay in large construction projects. *International Journal of Project Management, 24(4), 349-357.*

Assaf, S., Hassanain, M. A., & Al-Zahrani, S. (2015). Causes of contractors’ failure in industrial projects in Saudi Arabia. *Journal of Applied Science, Engineering and Technology, 9(3), 158-164.*

Austin, S. A., Baldwin, A. N., & Steele, J. L. (2002). Improving building design through integrated planning and control. *Engineering Construction and Architectural Management, 9(3), 249-258.*

Austin, S., Baldwin, A., Li, B., & Waskett, P. (1999). Analytical design planning technique: a model of the detailed building design process. *Design Studies, 20(3), 279-296.*

Austin, S., Baldwin, A., Li, B., & Waskett, P. (2000). Analytical design planning technique (ADePT): a dependency structure matrix tool to schedule the building design process. *Construction Management and Economics, 18(2), 173-182.*

Bachman, L. R. (2004). *Integrated Buildings: the systems basis of architecture (Vol. 9)*. John Wiley & Sons. Hoboken, NJ, U.S.A.

Bamardoof, S. M. (2015), Interview, General Manager at Al Raed Consultants, Al-Khobar, Eastern province, Saudi Arabia, October 21

Bhatla, A., & Leite, F. (2012). "Integration Framework of BIM with the Last Planner System TM.". *In IGLC 2012-20th Conference of the International Group for Lean Construction.*

Boshlibi, A. A. (2015), Interview, Senior Executive Manager at Afniah Consultants, Al-Khobar, Eastern province, Saudi Arabia, November 4

Boudeau, C. (2013). Design team meetings and the coordination of expertise: the roof garden of a hospital. *Construction Management and Economics, 31(1), 78-89.*

Chang, A. S., & Ibbs, W. (2006). System model for analyzing design productivity. *Journal of Management in Engineering, 22(1), 27-34.*

Chiu, M. L. (2002). An organizational view of design communication in design collaboration. *Design Studies, 23(2), 187-210.*

Choo, H. J., Hammond, J., Tommelein, I. D., Austin, S. A., & Ballard, G. (2004). DePlan: a tool for integrated design management. *Automation in Construction, 13(3), 313-326.*

Clark, G., & Mehta, P. (1997). Artificial intelligence and networking in integrated building management systems. *Automation in Construction, 6(5), 481-498.*

Construsction Specification Institutues (CSI). http://www.csinet.org.

de Blois, M., Herazo-Cueto, B., Latunova, I., & Lizarralde, G. (2011). Relationships between construction clients and participants of the building industry: Structures and mechanisms of coordination and communication. *Architectural Engineering and Design Management, 7(1), 3-22.*

Derek, T., & Clements-Croome, J. (1997). What do we mean by intelligent buildings?. *Automation in Construction, 6(5), 395-400.*

Dominowski, R. L. (1980), *Research Methods*, Prentice-Hall.Inc., Engle-wood Cliffs,N.J.

Dong, A. (2005). The latent semantic approach to studying design team communication. *Design Studies, 26(5), 445-461.*

Dong, A. (2007). The enactment of design through language. *Design Studies, 28(1), 5-21.*

El-Reifi, M. H., & Emmitt, S. (2013). Perceptions of lean design management. *Architectural Engineering and Design Management, 9(3), 195-208.*

Gray, C., & Hughes, W. (2001). *Building Design Management.* Routledge. Butterworth-Heinemann, Boston, MA, 2001.

Hammond, J. W., Choo, H. J., Tommelein, I. D., Austin, S. A., & Ballard, G. (2000). Integrating design planning, schedule and control with Deplan. *Proceedings 8th annual IGLC conference, Brighton.*

Hellmund, A. J., Van Den Wymelenberg, K. G., & Baker, K. (2008). Facing the challenges of integrated design and project delivery. *Strategic Planning for Energy and the Environment, 28(1), 69-80.*

Hamdi, A. (2015), Interview, Chief Executive Officer of Vision Engineering Consultants (VADO) , Al-Khobar, Eastern province, Saudi Arabia, October 11.

Horner, R. M. W., El-Haram, M. A., & Munns, A. K. (1997). Building maintenance strategy: a new management approach. *Journal of Quality in Maintenance Engineering, 3(4), 273-280.*

Humphreys, P., Matthews, J., & Kumaraswamy, M. (2003). Pre-construction project partnering: from adversarial to collaborative relationships. *Supply Chain Management: An International Journal, 8(2), 166-178.*

Ibbs, C. W., Kwak, Y. H., Ng, T., & Odabasi, A. M. (2003). Project delivery systems and project change: Quantitative analysis. *Journal of Construction Engineering and Management, 129(4), 382-387.*

Israelsson, N., & Hansson, B. (2009). Factors influencing flexibility in buildings. *Structural Survey, 27(2), 138-147.*

Janis, R. R., & Tao, W. K. (2013). Mechanical & Electrical Systems in Buildings. Pearson Higher Ed.

Konchar, M., & Sanvido, V. (1998). Comparison of US project delivery systems. *Journal of Construction Engineering and Management, 124(6), 435-444.*

Korman, T., & Tatum, C. B. (2000). Coordinating building systems: process and knowledge. *Journal of Architectural Engineering,6(4) 116-121.*

Korman, T. M., & Tatum, C. B. (2001). Development of a knowledge-based system to improve mechanical, electrical, and plumbing coordination.

Korman, T. M., Fischer, M. A., & Tatum, C. B. (2003). Knowledge and reasoning for MEP coordination. *Journal of Construction Engineering and Management, 129(6), 627-634.*

Korman, T. M., & Tatum, C. B. (2006a). Using construction,operations, and maintenance knowwledge to better coordinate mechanical,electrical, and plumbing systems in builidngs. *ASCE-Building integration solution, 1-9.*

Korman, T. M., & Tatum, C. B. (2006b). Prototype tool for mechanical,electrical, and plumbing coordination. *ASCE-Journal of Computing in Civil Engineering,20(1) 38-48.*

Korman, T. M. (2009). Rules and guidelines for improving the mechanical,electrical, and plumbing coordination process for buildings. *ASCE-Construction research congress, 999-1008.*

Korman, T., Simonian, L., & Speidel, E. (2008). Using Building Information Modeling to improve the mechanical, electrical, and plumbing coordination process for buildings. *In Proceedings of the AEI 2008 Conference, Colorado, USA.*

Korman, T. M. (2010). Improving the MEP coordination process through information sharing and establishing trust.

Korman, T., Simonian, L., & Speidel, E. (2010). How builidng information modeling has changed the MEP coordination process. *Challenges, Opportunities, and Solutions in Structural Engineering and Construction, 959-963.*

Korman, T. M., & Huey-king, L. (2013). Industry input for construction engineering and management courses: Development of the building systems coordination exercise for construction engineering and management students. *Practice Periodical on Structural Design and Construction, 19(1), 68-72.*

Kish, L. (1995). "*Survey Sampling*." New York, Johan Wiley and Sons Inc.

Ku, K., & Taiebat, M. (2011). BIM experiences and expectations: the constructors' perspective. *International Journal of Construction Education and Research, 7(3), 175-197.*

Lai, J. H., & Yik, F. W. (2007). Monitoring building operation and maintenance contracts. *Facilities, 25(5/6), 238-251.*

Leaman, A., & Bordass, B. (1993). Building design, complexity and manageability. *Facilities, 11(9), 16-27*

Lee, G. (2014). Parallel vs. sequential cascading MEP coordination strategies: a pharmaceutical building case study. *Automation in Construction, 43, 170-179*.

Lee, Y. C., Eastman, C. M., & Lee, J. K. (2015). Validations for ensuring the interoperability of data exchange of a building information model. *Automation in Construction, 58, 176-195.*

Leite, F., Akinci, B., & Garrett, J. (2009). Identification of data items needed for automatic clash detection in MEP design coordination. *Construction Research Congress (pp.416-425).*

Liu, A. W., & Melhado, S. B. (2010). Office Building Design Conception Guidelines. Proceedings: W096 - *Special Track 18th CIB World Building Congress, Salford, UK*

Liu, R., Issa, R. R. A., & Olbina, S. (2010). Factors influencing the adoption of building information modeling in the AEC Industry. *International Conference in Computing in Civil and Building Engineering, University of Nottingham, United Kingdom.*

Luk, B. L., Liu, L. K., & Collie, A. A. (2007). Climbing service robots for improving safety in building maintenance industry. *Proceedings of International Conference on Bioinspiration and Robotics: Walking and Climbing Robots pp. 127–146.*

Ma, Z., Cooper, P., Daly, D., & Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings, 55, 889-902*.

Masterman, J. W. E., & Gameson, R. N. (1994). Client characteristics and needs in relation to their selection of building procurement systems. East meets West, 221-228.

MacMillan, S., Steele, J., Kirby, P., Spence, R., & Austin, S. (2002). Mapping the design process during the conceptual phase of building projects. *Engineering Construction and Architectural Management, 9(3), 174-180.*

Medallah, A. (2015), Interview, Architectural design partner at AKM & Partners, Al-Khobar, Eastern province, Saudi Arabia,  October 22

Malatras, A., Asgari, A., Baugé, T., & Irons, M. (2008). A service-oriented architecture for building services integration. *Journal of Facilities Management, 6(2), 132-151.*

Mills, A., & Ashford, P. (2003). Cost factors affecting the design of ground-supported floors. *Structural Survey, 21(1), 22-28.*

Mills, F. T., & Glass, J. (2009). The construction design manager's role in delivering sustainable buildings. *Architectural Engineering and Design Management, 5(1-2), 75-90.*

Odusami, K. T. (2002). Perceptions of construction professionals concerning important skills of effective project leaders. *Journal of Management in Engineering, 18(2), 61-67.*

Olawale, Y. A., & Sun, M. (2010). Cost and time control of construction projects: inhibiting factors and mitigating measures in practice. *Construction Management and Economics, 28(5), 509-526.*

Olofsson, T., Lee, G., Eastman, C., & Reed, D. (2007). Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing.

Park, H., Meacham, B. J., Dembsey, N. A., & Goulthorpe, M. (2014). Integration of fire safety and building design. *Building Research and Information, 42(6), 696-709.*

Pennanen, A., Ballard, G., & Haahtela, Y. (2011). Target costing and designing to targets in construction. *Journal of Financial Management of Property and Construction, 16(1), 52-63.*

Rekola, M., Mäkeläinen, T., & Häkkinen, T. (2012). The role of design management in thesustainable building process. *Architectural Engineering and Design Management, 8(2),78-89.*

Riley, D. (2000). Coordination and production planning for mechanical, electrical and plumbing construction. Construction Congress; Building Together for a Better Tomorrow in an Increasingly Complex World.

Riley, D., & Horman, M. (2001). Effects of design coordination on project uncertainty. *Proceedings of the 9th Annual Conference of the International Group for Lean Construction (IGLC-9)*, Singapore.

Riley, D. R., Varadan, P., James, J. S., & Thomas, H. R. (2005). Benefit-cost metrics for design coordination of mechanical, electrical, and plumbing systems in multistory buildings. *Journal of Construction Engineering and Management, 131(8), 877-889.*

Ryd, N. (2004). The design brief as carrier of client information during the construction process. *Design Studies, 25(3), 231-249.*

Sacks, R., & Barak, R. (2008). Impact of three-dimensional parametric modeling of buildings on Productivity in structural engineering practice. *Automation in Construction, 17 (2008), 439-449.*

Sambasivan, M., & Soon, Y. W. (2007). Causes and effects of delays in Malaysian construction industry. *International Journal of Project Management, 25(5), 517-526.*

Santos, E., T. & Ferreira, R. C. (2008). Building design coordination: computing 2D and 3D methods. *International Conference on Information Technology in Construction,CIB W78.*

Sawhney, A. & Maheswari, J. U. (2013). Design coordination using cloud-based smart builidng element models. *International Journal of Computer Information Systems and Industrial Management Applications,5(2013) 445-453.*

Sebastian, R. (2006). Evaluating a proposed approach for managing collaborative design in the conceptual design phase. *Architectural Engineering and Design Management, 2(3), 216-224.*

Senaratne, S., & Gunawardane, S. (2015). Application of team role theory to construction design teams. *Architectural Engineering and Design Management, 11(1), 1-20.*

Senescu, R., Mole, A., & Fresquez, A. (2006). A case study in structural drafting,analysis and design using an integrated intelligent model. *Joint International Conference on Computing and Decision Making in Civil and Building Engineering*.

Shen, Q., Li, H., Chung, J., & Hui, P. Y. (2004). A framework for identification and representation of client requirements in the briefing process. *Construction Management and Economics, 22(2), 213-221.*

Siddiqui, S. M. (2015), Interview, Architects at Saudi Technologist Consulting Engineering, Al-Khobar, Eastern province, Saudi Arabia, October 28

Singh, M. M., Sawhney, A., & Borrmann, A. (2015). Modular Coordination and BIM: Development of Rule Based Smart Building Components. *Procedia Engineering, 123, 519-527.*

Sommerville, J., & Craig, N. (2005). Intelligent buildings with radio frequency identification devices. *Structural Survey, 23(4), 282-290.*

Sonnenwald, D. H. (1996). Communication roles that support collaboration during the design process. *Design Studies, 17(3), 277-301.*

Sweis, G., Sweis, R., Hammad, A. A., & Shboul, A. (2008). Delays in construction projects: The case of Jordan. *International Journal of Project Management, 26(6), 665-674.*

Tabesh, R. A., & Staub-French, S. (2005). Case study of constructability reasoning in MEP coordination, *ASCE-Construction Research Congress, 1-9.*

The Construction Specifications Institute (CSI), (2011). Construction Specifications: Practice Guide, The Construction Specifications Institute, John Wiley & Sons, Inc.

Thomas, H. R., Korte, C. Q., Sanvido, V. E., & Parfitt, M. K. (1999). Conceptual model for measuring productivity of design and engineering. *Journal of Architectural Engineering, 5(1),1-7.*

Tinari, J. A. (2015), Interview, Director of Architecture at Jacobs, Zamel, & Turbag Consulting Engineers (Jacobs Zate) , Al-Khobar, Eastern province, Saudi Arabia, October 18

Tunstall, G. (2006). Managing the building design process. Routledge.

Tzortzopoulos, P., & Cooper, R. (2007). Design management from a contractor's perspective: The need for clarity. *Architectural Engineering and Design Management, 3(1), 17-28*

Wan, S. K. M., & Kumaraswamy, M. M. (2012). Improving building services coordination at the pre-installation stage. *Engineering, Construction and Architectural Management, 19(3), 235-252.*

Wang, L., & Leite, F. (2015). Process Knowledge Capture in BIM-Based Mechanical,Electrical, and Plumbing Design Coordination Meetings. *Journal of Computing in Civil Engineering, 04015017.*

Wang, L., & Leite, F. (2013). Knowledge discovery of spatial conflict resolution philosophies in BIM-enabled MEP design coordination using data mining techniques: a proof-of-concept. *Proceedings of the ASCE International Workshop on Computing in Civil Engineering (WCCE'13) (pp. 419-426).*

Wang, J., Chong, H. Y., Shou, W., Wang, X., & Guo, J. (2014). BIM-Enabled Design Collaboration for Complex Building. *Cooperative Design, Visualization, and Engineering (pp.238-244).*

Wilkins, C., & Kiviniemi, A. (2008). Engineering-centric BIM. *ASHRAE Journal, 50(12), 44-48.*

Yu, A. T., Shen, Q., Kelly, J., & Hunter, K. (2006). Investigation of critical success factors in construction project briefing by way of content analysis. *Journal of Construction Engineering and Management, 132(11), 1178-1186.*

Yung, P., Wang, J., Wang, X., & Jin, M. (2014). A bim-enabled MEP coordination process for use in china. *Journal of Information Technology in Construction,19(2014) 383-398.*

Zanni, M. A., Soetanto, R., & Ruikar, K. (2014). Defining the sustainable building design process: methods for BIM execution planning in the UK. *International Journal of Energy Sector Management, 8(4), 562-587.*

Zavadskas, E., Raslanas, S., & Kaklauskas, A. (2008). The selection of effective retrofit scenarios for panel houses in urban neighborhoods based on expected energy savings and increase in market value: The Vilnius case. *Energy and Buildings, 40(4), 573-587.*

Zerjav, V., Hartmann, T., & Achammer, C. (2013). Managing the process of interdisciplinary design: identifying, enforcing, and anticipating decision-making frames. *Architectural Engineering and Design Management, 9(2), 121-133.*

# APPENDIX 1

Investigation of the Local Current Practice of Building coordination process/practice through interview.

**Questions for A/E:**

1. What is your scope of practice at the A/E office? (check all that applies)
   - ☐ Architectural designer.
   - ☐ Project manager.
   - ☐ Building design coordinator.
   - ☐ All of the above.
   - ☐ Others (specify) ……………………………………………………

2. Please give me a brief description of your current building design coordination process and how it’s initiated at each stage of the design development?
   - 30% design stage……………………………………..
     - ☐ Workshops
     - ☐ Informal meetings
     - ☐ Formal meetings
     - ☐ Others………………………………………….
   - 60% design stage……………………………………….
     - ☐ Workshops
     - ☐ Informal meetings
     - ☐ Formal meetings
     - ☐ Others………………………………………….
   - 90% design stage……………………………………….
     - ☐ Workshops
     - ☐ Informal meetings
     - ☐ Formal meetings
     - ☐ Others………………………………………….
   - 95% design stage……………………………………….
     - ☐ Workshops
     - ☐ Informal meetings
     - ☐ Formal meetings
     - ☐ Others………………………………………….
   - Others (specify)………………………………………

3. From your practice, identify all parties that participate in the building services coordination process? And what is the role of each one?
   - ☐ Architect/designer.

    - Concept design
    - Detailed design
    - Others (specify)………………………………..
- ☐ Structural engineers.
    - Structural components design
    - Others (specify)………………………………..
- ☐ MEP engineers.
    - Mechanical, electrical and plumbing design.
    - Others (specify)………………………………..
- ☐ GC-MEP coordinator.
    - Coordinates all sub-contractors and MEP drawings
    - Coordinates all drawings from team members
    - Others (specify)………………………………..
- ☐ Others (please specify)……………………………….…

**4.** From your practice, please indicate the methods of communications during the coordination process?

- ☐ Workshops at different stages of the process.
- ☐ Informal meetings with all participants.
- ☐ Formal meetings with all participants.
- ☐ Others (please specify)…………………………………………

**5.** What type of tools is adopted in your coordination process?

- ☐ Building information model (BIM)
- ☐ Light table tracing for 2D drawings.
- ☐ Others (specify) ………………………………………………..

**6.** From your practice, how do you collect different building coordination stakeholders' information?

- ☐ Through their representative.
- ☐ Through the project manager/coordinator.
- ☐ Through a workshop with all of them.
- ☐ Others (specify) ………………………………………………

**7.** In your current practice, when would the coordination activities be finalized?

- ☐ After the detail design phase.
- ☐ At the completion of the design process
- ☐ After the completion of the pre-installation stage
- ☐ After the completion of the construction.
- ☐ Others (specify) ………………………………………………..

**8.** What are the responsibilities of the design coordinator?

- ☐ Controlling the coordination process.
- ☐ Ensuring that the identified requirements will be included in the final coordinated design.
- ☐ Others (please specify)……………………………………….

**9.** What is the significance of the coordination process?

- ☐ Ensure error free construction documents.
- ☐ Ensure the completion of design phase.
- ☐ To eradicate all form of building systems clashes.
- ☐ Others (specify)……………………………………………..

**10.** In your practice, the design coordinators are?

- ☐ The Architect.
- ☐ The Project manager.
- ☐ The MEP engineers.
- ☐ The GC-MEP coordinator.
- ☐ All of the above.
- ☐ Others (specify)………………………………………………...

**11.** From your daily practice, what are the consequences of inefficient/poor building services coordination?

- ☐ Rework on construction site
- ☐ Increase waste caused by demolition on site
- ☐ Increase project time
- ☐ Increased project cost
- ☐ Increased design change orders
- ☐ Reduced durability of systems
- ☐ Others (please specify)…………………………………………………..

**12.** From your practice, what are the challenges that affect the process of effective coordination?

- ☐ Design complexities.
- ☐ Managing multiple professional
- ☐ Time allocated for the design process
- ☐ Budget allocated for the entire coordination process
- ☐ Unclear goals and requirements (from professionals)
- ☐ Setting priorities among the requirements and professionals.
- ☐ Others (please specify)…………………………………………………..

**13.** Do you have a process for receiving feedback of errors caused by bad coordination from construction site and completed projects?

- ☐ Yes
- ☐ No

If yes, please explain………………………………………………………

**14.** Please suggest ways for improvement of building coordination process?

- ☐ Adoption of efficient tools and technology.
- ☐ Recruitment of experienced team
- ☐ Proactive and effective time management.
- ☐ Team work / ambition.
- ☐ Detailed review at every stage of the design process (30%, 60%, 90%)
- ☐ Others (specify)…………………………………………………

## APPENDIX 2

**King Fahd University Of Petroleum and Minerals**
**College of Environmental Design**
**Architectural Engineering Department**

Date: December 27, 2015
Dear Sir,

**Factors influencing the effective coordination of building services during the design development and review stages.**

The building services coordination can be defined as management of interdependencies and the arrangement of building services components to fit into the constraints of the building architecture and structure. The coordination exercise is therefore affected by several factors. In this study, the researcher aims to identify and assess the factors that influence the practices of effective coordination of building services during the design developing and review stages of building projects. The Questionnaire consists of two parts. Part one includes general information about the respondents. Part Two includes the assessment of the factors. Your input to this questionnaire will lead to a better understanding of these factors. Any information obtained through this questionnaire will stringently be used for educational purposes only.

Thank you.

Please return this questionnaire once filled to the following address:

Babatunde Adewale,
Architectural Engineering Department,
King Fahd University of Petroleum and Minerals,
Dhahran 31261,
Saudi Arabia.
E-mail: talk.tunde@gmail.com or g201305050@kfupm.edu.sa
Mobile: 050750431

# Questionnaire Survey

**Part One:** General Information

1) Respondent Information:

| | |
|---|---|
| Name (Optional) | |
| Office or Company Name | |
| Phone | |
| Fax | |
| E-Mail Address | |
| Office or Company Address | |

2) Years of Experience:

| | | | |
|---|---|---|---|
| ☐ | Less than 5 years | ☐ | 5 – 10 years |
| ☐ | 10 – 20 years | ☐ | Over 20 years |

3) Respondent Position:

| | |
|---|---|
| ☐ | Design Coordinator |
| ☐ | Contractor |
| ☐ | Facilities Manager |
| ☐ | Other (please specify)________________________ |

**4)** Type of Projects that you mainly worked on:

| | |
|---|---|
| ☐ | Residential Buildings (high-rise of 20+ floors) |
| ☐ | Residential Buildings (low-rise) |

| | |
|---|---|
| ☐ | Educational Buildings |
| ☐ | Office Buildings |
| ☐ | Recreational Buildings |
| ☐ | Sports Buildings |
| ☐ | Commercial Buildings |
| ☐ | Other (please specify)________________________________ |

**Part Two:** Assessment of Factors Affecting the Effective Coordination of Building Services during the Design Development and Review Stages

| Factors Affecting the Effective Coordination of Building Services during the Design Development and Review Stages | | Importance Level | | | | |
|---|---|---|---|---|---|---|
| | | Extremely Important | Very Important | Important | Somewhat Important | Not Important |
| **A. Factors Related to the Planning Phase of the Project** | | | | | | |
| 01. | The scale and complexity of the project. | | | | | |
| 02. | The schedule of the project. | | | | | |
| 03. | The allocated budget for the project. | | | | | |
| 04. | The location of the project. | | | | | |
| 05. | Availability of clear Architectural program | | | | | |
| | Other (please specify) | | | | | |
| **B. Factors Related to the Design of Mechanical/Electrical/Plumbing Systems** | | | | | | |
| 06. | The quality of the preliminary/conceptual design of the building project. | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 07. | The type and occupancy requirements of the building project. | | | | | |
| 08. | The design complexity of the MEP systems for the building project. | | | | | |
| 09. | The process of exchanging data, information and design outputs among MEP systems. | | | | | |
| 10. | The aesthetic required when integrating the MEP systems into the Architecture & structural systems. | | | | | |
| 11. | The cost of the specified MEP systems for the building projects. | | | | | |
| 12. | The performance of the MEP systems specified for the building project. | | | | | |
| 13. | The detailing of various components of the MEP systems. | | | | | |
| | Other (please specify) | | | | | |
| **C. Factors Related to the Construction of Mechanical/Electrical/Plumbing Systems** | | | | | | |
| 14. | The material used in fabricating the MEP system specified for the building project. | | | | | |
| 15. | The required clearance for the MEP systems specified for the building project. | | | | | |
| 16. | The connection support used during installation of the MEP systems. | | | | | |
| 17. | The space allocated for the installation for the MEP systems in the building. | | | | | |
| 18. | The allocated time for the fabrication of the MEP systems' components. | | | | | |
| 19. | Testing requirements of the MEP systems during construction. | | | | | |
| 20. | The installation sequence of the MEP systems. | | | | | |
| 21. | Safety considerations during the installation of | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | MEP systems. | | | | | |
| | Other (please specify) | | | | | |
| **D. Factors Related to the Operation and Maintenance of Mechanical/ Electrical/ Plumbing Systems** | | | | | | |
| 22. | Access to the various components of the MEP systems. | | | | | |
| 23. | Safety requirements during the operation and maintenance of MEP systems. | | | | | |
| 24. | The expandability and retrofit requirements of the MEP systems' components. | | | | | |
| 25. | Availability of the spare parts required for the maintenance of MEP systems. | | | | | |
| 26. | Availability of Building management systems (BMS) | | | | | |
| | Other (please specify) | | | | | |
| **E. Factors Related to the Owner** | | | | | | |
| 27. | The clarity of the requirements & objectives provided by the owner. | | | | | |
| 28. | The type of project ownership. | | | | | |
| 29. | The frequency of alterations demanded by the owner. | | | | | |
| 30. | The project delivery system adopted for the building project. | | | | | |
| 31. | Honoring agreed upon payment schedules. | | | | | |
| | Other (please specify) | | | | | |
| **F. Factors Related to the Design Team and the Tools Used** | | | | | | |
| 32. | The level of experience of the design team. | | | | | |
| 33 | The capacity of the firm handling the project | | | | | |
| 34. | The comprehensiveness of the software utilized | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | for the building design. | | | | | |
| 35 | The software literacy level of the design team. | | | | | |
| 36 | Communication skills of the design team members. | | | | | |
| | Other (please specify) | | | | | |
| **Other (Please Specify)** | | | | | | |
| 1. | | | | | | |
| 2. | | | | | | |
| 3. | | | | | | |
| 4. | | | | | | |

## Thank you

# استبيان

## الجزء الأول (معلومات عامة)

**1-بيانات المشترك**

| | |
|---|---|
| الاسم (اختياري) | |
| المكتب أو اسم الشركة | |
| الهاتف | |
| الفاكس | |
| البريد الالكتروني | |
| عنوان المكتب أو الشركة | |

**2- سنوات الخبرة :**

| | | | |
|---|---|---|---|
| ما بين 5 إلى 10 سنوات | ☐ | أقل من (5) سنوات | ☐ |
| أكثر من (20) سنة | ☐ | ما بين (10)- (20) سنة | ☐ |

**3-معلومات عن وظيفة المشترك**

| | |
|---|---|
| ☐ | منسق تصميم |
| ☐ | مقاول |
| ☐ | مدير مرافق |
| ☐ | غير ذلك...من فضلك حددها: |

**4-نوع المشروع الرئيسي الذي تعمل فيه**

| | |
|---|---|
| ☐ | مباني سكنية (مستوى مرتفع أعلى من 20 دور) |
| ☐ | مباني سكنية (مستوى ارتفاع منخفض) |
| ☐ | مباني تعليمية |
| ☐ | مباني مكتبية |
| ☐ | مباني ترفيهية |
| ☐ | مباني رياضية |
| ☐ | مباني تجارية |
| ☐ | غير ذلك...من فضلك حددها: |

**الجزء الثاني: تقييم العوامل المؤثرة على التنسيق الفعال لخدمات المباني أثناء تطوير التصميم ومراحل المراجعة**

| | العوامل المؤثرة على التنسيق الفعال لخدمات المباني أثناء تطوير التصميم ومراحل المراجعة | درجة الأهمية | | | | |
|---|---|---|---|---|---|---|
| | | مهم بدرجة كبيرة جداً | مهم جدا | مهم | ألى حد ما مهم | غير مهم |
| **أ-العوامل المتعلقة بمرحلة تخطيط المشروع** | | | | | | |
| -1 | حجم ودرجة صعوبة أو تعقيد المشروع | | | | | |
| -2 | الجدول الزمني للمشروع | | | | | |
| -3 | الميزانية المخصصة للمشروع | | | | | |
| -4 | موقع المشروع | | | | | |
| -5 | مدى إتاحة وتوفير برنامج معماري واضح | | | | | |
| | عوامل أخر (حددها من فضلك) | | | | | |
| **ب-العوامل المتعلقة بتصميم الأنظمة الميكانيكية والكهربائية والسباكة (MEP)** | | | | | | |
| 6 | مدى كفاءة التصميم المبدئي/ التصميم التصوري لمبنى المشروع | | | | | |
| 7 | نوع مبنى المشروع ومتطلبات إشغاله | | | | | |
| 8 | مدى تعقيد التصميم الخاص بالأنظمة الميكانيكية والكهربائية والسباكة الخاص بمبنى المشروع | | | | | |
| 9 | عملية تبادل البيانات والمعلومات وتصميم المخرجات بين الأنظمة الميكانيكية والكهربائية والسباكة | | | | | |
| 10 | الناحية الجمالية المطلوبة عند دمج الأنظمة الميكانيكية والكهربائية والسباكة مع الأنظمة المعمارية والإنشائية | | | | | |
| 11 | تكلفة الأنظمة الميكانيكية والكهربائية والسباكة المحددة لمبنى المشروع | | | | | |
| 12 | أداء الأنظمة الميكانيكية والكهربائية والسباكة المحدد لمبنى المشروع | | | | | |
| 13 | تفاصيل مكونات أخرى متعددة والخاصة بالأنظمة الميكانيكية والكهربائية والسباكة | | | | | |
| | عوامل أخر (حددها من فضلك) | | | | | |
| **ج- العوامل المتعلقة بإنشاء الأنظمة الميكانيكية والكهربائية والسباكة** | | | | | | |
| 14 | المادة المستخدمة لتفصيل وعمل الأنظمة الميكانيكية والكهربائية والسباكة المخصصة لمبنى المشروع | | | | | |
| 15 | الفسح اللازم للأنظمة الميكانيكية والكهربائية والسباكة المخصصة لمبنى المشروع | | | | | |
| 16 | دعم الارتباط المستخدم أثناء تركيب الأنظمة الميكانيكية والكهربائية والسباكة المخصصة لمبنى المشروع | | | | | |
| 17 | المساحة المخصصة لتركيب الأنظمة الميكانيكية والكهربائية والسباكة المخصصة لمبنى المشروع | | | | | |
| 18 | الوقت المحدد لتفصيل مكونات الأنظمة الميكانيكية والكهربائية والسباكة | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 19 | متطلبات الفحص والاختبار للأنظمة الميكانيكية والكهربائية والسباكة أثناء الإنشاء | | | | | |
| 20 | تتابع وتسلسل التركيب الخاص بالأنظمة الميكانيكية والكهربائية والسباكة | | | | | |
| 21 | الاعتبارات والاحتياطات الأمنية المتخذة عند تركيب الأنظمة الميكانيكية والكهربائية والسباكة | | | | | |
| | عوامل أخر (حددها من فضلك) | | | | | |
| **د- العوامل المتعلقة بتشغيل وصيانة الأنظمة الميكانيكية والكهربائية والسباكة** | | | | | | |
| 22 | إمكانية الدخول والوصول إلى المكونات المختلفة للأنظمة الميكانيكية والكهربائية والسباكة . | | | | | |
| 23 | المتطلبات الأمنية اللازمة عند تشغيل وصيانة الأنظمة الميكانيكية والكهربائية والسباكة | | | | | |
| 24 | متطلبات التمدد وإدخال الإصلاحات الخاصة بمكونات الأنظمة الميكانيكية والكهربائية والسباكة | | | | | |
| 25 | مدى إتاحة وتوفر قطع الغيار المطلوبة لصيانة الأنظمة الميكانيكية والكهربائية والسباكة | | | | | |
| 26 | مدى توفر وإتاحة أنظمة إدارة المبني (BMS) | | | | | |
| | عوامل أخر (حددها من فضلك) | | | | | |
| **هـ-العوامل المتعلقة بالمالك** | | | | | | |
| 27 | مدى وضوح المتطلبات والأهداف التي يحتاج إليها المالك | | | | | |
| 28 | نوع ملكية المشروع | | | | | |
| 29 | مدى تتابع وتسلسل التغييرات التي يطلبها المالك | | | | | |
| 30 | نظام التسليم المتبع لمبنى المشروع | | | | | |
| 31 | احترام الجدول الزمني الخاص بالدفع | | | | | |
| | عوامل أخر (حددها من فضلك) | | | | | |
| **م-العوامل المتعلقة بفريق التصميم والأدوات المستخدمة** | | | | | | |
| 32 | مستوى الخبرة الخاص بفريق التصميم | | | | | |
| 33 | مدى الطاقة الاستيعابية للشركة المنظمة للمشروع | | | | | |
| 34 | مدى شمولية وتكامل السوفت وير المستخدم في تصميم المبنى | | | | | |
| 35 | مستوى الدراية والعلم بالسوفت وير الخاص بفريق التصميم | | | | | |
| 36 | مهارات التواصل بين أعضاء فريق التصميم | | | | | |
| | عوامل أخر (حددها من فضلك) | | | | | |
| **عوامل أخرى غير المذكور أعلاه (حددها من فضلك)** | | | | | | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |

**مع الشكر والتقدير،،،،**

# APPENDIX 3

**King Fahd University Of Petroleum and Minerals**
**College of Environmental Design**
**Architectural Engineering Department**

Date: March 30, 2016
Dear Sir,

**Assessment of a Framework for the effective coordination of MEP services during the design development and review stages**

A framework for the effective coordination of MEP services during the design development and review stages has been developed, as part of my Master thesis in the Architectural Engineering graduate program. The developed framework consists of five sequential processes as follows:

- Develop the Project Conceptual Design
- Develop the Preliminary Design of MEP Services
- Prepare the Developed Design of MEP Services
- Prepare the Detailed Design of MEP Services
- Prepare the Construction Documents of MEP Services

Your input in assessing the importance of the developed framework will help to confirm its practicality and usefulness to the Architectural/Engineering (A/E) practice, in particular and the building industry at large. A questionnaire survey is enclosed. The questionnaire consists of two parts. Part one includes general information about the respondents. Part two includes the assessment of the developed framework. Any information obtained through this questionnaire will stringently be used for educational purposes only.

Thank you.

Please return this questionnaire once filled to the following address:
Babatunde Adewale,
Architectural Engineering Department,
King Fahd University of Petroleum and Minerals,
Dhahran 31261, Saudi Arabia.
E-mail: talk.tunde@gmail.com
Mobile: 050750431

# Questionnaire Survey

**Part One:** General Information

1) Respondent Information:

| | |
|---|---|
| Name (Optional) | |
| Office or Company Name | |
| Phone | |
| Fax | |
| E-Mail Address | |
| Office or Company Address | |

2) Years of Experience:

| | | | |
|---|---|---|---|
| ☐ | Less than 5 years | ☐ | 5 – 10 years |
| ☐ | 10 – 20 years | ☐ | Over 20 years |

3) Respondent Position:

| | |
|---|---|
| ☐ | Design Coordinator |
| ☐ | Other (please specify)_______________________ |

**4)** Type of Projects that you mainly worked on:

| | |
|---|---|
| ☐ | Residential Buildings (high-rise of 20+ floors) |
| ☐ | Residential Buildings (low-rise) |
| ☐ | Educational Buildings |
| ☐ | Office Buildings |

| | |
|---|---|
| ☐ | Recreational Buildings |
| ☐ | Sports Buildings |
| ☐ | Commercial Buildings |
| ☐ | Other (please specify)________________________________ |

**Part Two:** Assessment of a framework for the effective coordination of MEP services during the design development and review stages.

Please select among the following importance terms to indicate the level of importance for each of the following Architectural/Engineering (A/E) practices.

Extremely Important = E.I.

Very Important = V.I.

Important = I.

Somewhat Important = S.I.

Not Important = N.I.

| Steps of the Framework for the effective coordination of MEP services during the design development and review stages | | Level of Importance | | | | | Do you perform this function in your firm? | |
|---|---|---|---|---|---|---|---|---|
| **Project Conceptual Design Phase** | | **E.I** | **V.I.** | **I.** | **S.I.** | **N.I** | **Yes** | **No** |
| 1. | Project consultants' selection with the client. | | | | | | | |
| 2. | Preparation of initial MEP requirements for the project. | | | | | | | |
| 3. | Development and evaluation of alternative MEP proposals. | | | | | | | |

| | | E.I | V.I. | I. | S.I. | N.I | Yes | No |
|---|---|---|---|---|---|---|---|---|
| 4. | Preparation of conceptual cost estimates for the MEP proposals. | | | | | | | |
| 5 | Review of MEP proposals with the client. | | | | | | | |
| **Project MEP Preliminary Design Phase** | | **E.I** | **V.I.** | **I.** | **S.I.** | **N.I** | **Yes** | **No** |
| 1. | Review of client selected MEP design proposal. | | | | | | | |
| 2. | Updating of the cost estimate of the selected MEP proposal. | | | | | | | |
| 3. | Coordination of MEP design information among the design team members. | | | | | | | |
| **Project MEP Developed Design Phase** | | **E.I** | **V.I.** | **I.** | **S.I.** | **N.I** | **Yes** | **No** |
| 1. | Conclusion of the selection of MEP services for the project | | | | | | | |
| 2. | Preparation of drawings and specifications for the MEP services | | | | | | | |
| 3. | Re-coordination of all MEP design information among the design team members. | | | | | | | |
| **Project MEP Detail Design Phase** | | **E.I** | **V.I.** | **I.** | **S.I.** | **N.I** | **Yes** | **No** |
| 1. | Development of all detailed designs for the MEP services. | | | | | | | |
| 2. | Developments of all the detailed specifications for the MEP services. | | | | | | | |
| 3. | Updating of the cost estimate of the MEP services. | | | | | | | |
| 4. | Review of the detailed design and specifications with the client. | | | | | | | |
| 5. | Re-Coordination of all MEP design information among the design team members. | | | | | | | |
| **Project MEP Construction Document Phase** | | **E.I** | **V.I.** | **I.** | **S.I.** | **N.I** | **Yes** | **No** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1. | Development of all MEP construction drawings. | | | | | | | |
| 2. | Review of all prepared MEP construction drawings. | | | | | | | |
| 3. | Coordination of the Architectural/Structural design with all MEP construction drawings. | | | | | | | |
| 4. | Final review of the construction documents and refinement the cost estimate for all MEP services. | | | | | | | |

**Thank you**

# Vitae


Name :Babatunde Olusegun Adewale

Nationality :Nigerian

Telephone : +2348091605555; +2348065922994

Email : talk.tunde@gmail.com / babatundeadewale@live.com

Address :Adot5 Limited. , Abuja, Nigeria


Academic Background :

**King Fahd University of Petroleum and Minerals | KSA.** [2013-2016]

**MSc** Architectural Engineering [Facilities Engineering and Management Specialization]

- King Fahd University of Petroleum & Minerals full Masters Scholarship Award | August 2013
- Best Administrative Staff Award | I.O. Limited | Lagos, Nigeria | Dec. 2010

**University of Lagos | Lagos, Nigeria.** [2003-2006]

**BSc** [Hons] Architecture

- Vice Chancellor's Prize for the Faculty Best Performance | December 2006
- Dean's Prize for the Faculty Best Student | December 2006
- Faculty Prize for Best All-Round Performance | December 2006
- Arc. Abubaker Prize for Best Graduating Architecture Student | December 2006
- Dean of Student Scholarship Award | February 2006
- Arc. Balogun Prize for the Best Design Portfolio | December 2005

**The Polytechnic Ibadan | Oyo, Nigeria.** [1999-2002]

**HND** Architectural Technology

- NBANE PRIZE for the Best Graduating Student in Architectural Technology | September 2002
- Best Architectural graphics Student | September 1999
- Oyo State Scholarship Award for Academic excellence | February 1999