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"Factors Affecting the Testing and Commissioning in Construction Projects and its Consequences"

Submitted by:
Ahmed Khalid Feda
B.Sc. Mechanical Engineering, UQU, 2017
Advisor Committee:
Ass. Prof. Yasser Aboel-Magd
Head of Civil Engineering Department, College of Engineering, University of Business and Technology, Jeddah, Saudi Arabia.

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ABSTRACT

Construction industry is growing very fast, and projects became very complex in their systems, equipment's and the technology being used. From here testing and commissioning interferes to ensure the functionality and performance of these systems and equipment's in accordance to its design and manufactural requirements. This case study subject is about the factors affecting testing and commissioning for construction projects in general, including the consequences of the factors and some possible solutions to prevent it. Moreover, the study was based on a questionnaire that contains 25 factors affecting the testing and commissioning and, those factors were identified by (the researcher as a testing and commissioning engineer, previous literature reviews and, specialized experienced testing and commissioning engineers and by the contributions of the questionnaire respondents). The study questionnaire collected 135 complete responses in the duration of almost two weeks, through respondents in Saudi Arabia with variation of different (nationalities, organizations, level of experiences and, job titles), and used a five-point ranking technique to rank the factors by the mean of the respondents ratings for each factor. Furthermore, the study indicates that the highest mean factor that affect testing and commissioning is "Project Specification" with a mean of 4.526, and the lowest mean factor is "Criteria of the snag list" with a mean of 3.348. However, regardless of the ranking of the factors. It seems that all the factors have a significant impact on testing and commissioning, as the minimum mean for all the 25 factors is "3.348" and the overall mean is "3.91", which are consider relatively high. Also, the study discussed the 10 highest ranked affecting factors consequences and offered some possible solutions, in addition of offering 6 recommendations to increase the testing and commissioning efficiency.

Keywords: Testing and commissioning, Construction projects, Factors affecting testing and commissioning.

الملخص

تشهد صناعة الإنشاءات نموًا سريعًا، وأصبحت المشاريع أكثر تعقيدًا من حيث الأنظمة والمعدات والتكنولوجيا المستخدمة. ومن هنا تبرز أهمية عمليات الاختبار والتشغيل لضمان كفاءة وأداء هذه الأنظمة والمعدات وفقًا لمتطلبات التصميم والمواصفات التصنيعية. تتناول هذه الدراسة العوامل المؤثرة على الاختبار والتشغيل في مشاريع الإنشاءات بشكل عام، بما في ذلك نتائج هذه العوامل وبعض الحلول الممكنة للحد من تأثيرها السلبي. استندت الدراسة إلى استبيان شمل 25 عاملاً مؤثرًا تم تحديدها من قبل الباحث (كخبير في مجال الاختبار والتشغيل)، ومن خلال مراجعة الدراسات السابقة، بالإضافة إلى آراء مهندسين متخصصين ذوي خبرة، ومساهمات المشاركين في الاستبيان. تم جمع 135 استجابة مكتملة للاستبيان خلال فترة تقارب أسبوعين، من مشاركين في المملكة العربية السعودية ينتمون إلى جنسيات ومؤسسات ومستويات خبرة ومسميات وظيفية متنوعة. استخدمت الدراسة تقنية التصنيف الخماسي لتحديد ترتيب العوامل بناءً على متوسط تقييمات المشاركين لكل عامل. أظهرت النتائج أن العامل الأعلى تأثيرًا على الاختبار والتشغيل هو "مواصفات المشروع" بمتوسط 4.526، بينما كان العامل الأقل تأثيرًا هو "معايير قائمة الملاحظات" بمتوسط 3.348. ومع ذلك، تشير النتائج إلى أن جميع العوامل لها تأثير ملحوظ، حيث بلغ الحد الأدنى لمتوسط التقييمات لجميع العوامل 3.348، بينما كان المتوسط العام 3.91، مما يعتبر مرتفعًا نسبيًا. كما ناقشت الدراسة العواقب المترتبة على أعلى 10 عوامل مؤثرة، واقترحت بعض الحلول الممكنة لمعالجتها. بالإضافة إلى ذلك، قدمت الدراسة 6 توصيات لتعزيز كفاءة عمليات الاختبار والتشغيل.

الكلمات المفتاحية: الاختبار والتشغيل، مشاريع الإنشاءات، العوامل المؤثرة على الاختبار والتشغيل.

INTRODUCTION:

Now some days the construction industry is growing very fast, and projects became very complex in their systems, equipment's and the technology being used. From here testing and commissioning interferes to ensure the functionality and performance of these systems and equipment's in accordance to its design and manufactural requirements.

Testing and commissioning is the last part of construction projects phases before the handover, and it involves the testing of MEP (Mechanical, Electrical and Plumping) equipment's and some architectures elements. In addition to the commissioning of the facility controlling and monitoring systems integrated with this equipment's. Also, this period includes the handing over of (Operation, Maintenance manuals and As -Built Drawings) and other documents to the owner or end user. As well as, the end user staff will receive a technical training for the facility installations and a completion certificate will be issued for the contractor after the final handover of the facility (Rumane, 2011).

On the other hand, some view testing and commissioning as a luxury and added cost especially in small and medium size projects. However, it's the complete opposite of that, as testing and commissioning is very essential to ensure that all equipment's are balanced, calibrated and systems are integrated and working smoothly in its perfect condition as designed. Furthermore, during the testing and commissioning period a lot of issues and problems will appear and it will be easier to solve it in that time while all the parties involved in the construction are available, and the facility is still not handed over to the end user.

PROBLEM STATEMENT

Testing and commissioning is a very important phase of projects life cycle, starting from mega projects to small domestic projects. Almost all the mega projects have testing and commissioning phase defined on its specification by a procedure. However, the problem is the fully and correct implementation of these procedures and tests by an expert third party and consultant engineer. On the other hand, small to medium projects testing and commissioning may not be required, and even if it's required and existed usually it will be very weak with its procedures and the type of tests conducted.

The weak implementation or non-implementation of testing and commissioning in construction projects, will result to huge losses of operating and maintaining these projects and buildings. Not only that, this issue will also affect the building performance, and it will affect the (safety, security and comfortability) of its occupants.

According to Energy Efficiency Factsheet (2005). Experience has shown that the non-implementation of commissioning in buildings will cost 8 to 20 percent more to operate than a commissioned building. In addition, on average the cost of performing commissioning was paid back in 4.8 years from energy savings alone.

STUDY OBJECTIVES:

The objective of the study is to evaluate and rate all the determined factors affecting testing and commissioning in the construction projects and identify the most affecting ones. Thus, determine and discuss some of the causes of these factor, possible solutions and, the consequences of having these factors affecting the testing and commissioning in construction projects. All of this is to show importance of testing and commissioning and its effect on buildings (performance, functionality operation, maintenance, safety and security).

STUDY LIMITATIONS:

The study results and analysis are based on the questionnaire that was made and distributed to engineers and managers in the privet and governmental sectors in Saudi Arabia. Thus, the results are mostly limited to the experiences of the respondents inside Saudi Arabia regarding testing and commissioning. In addition, there is not much studies and researches that was found with relevant to testing and commissioning especially for studies regarding factors affecting it

in the construction projects, and most of the available ones are old studies. That's made the data collection much harder. Also, the amount of the respondents to the questionnaire or the sample size is relatively small, a bigger sample size would make the study more confident. Finally, the number of the respondents that their current job is related to testing and commissioning were 62% only, and if the percentage was higher it would make the study more accurate.

THEORETICAL FRAMEWORK:

Buildings commissioning is a process to verify and ensure that building systems and equipment's are functioning as designed and they met the end user requirements. The initial costs of commissioning are high. Yet it will be recovered through operating and maintenance cost savings and through the trained improved staff performance (Energy Efficiency Factsheet, 2005)

This section present's the beginnings of testing and commissioning. As well, testing and commissioning definition, types, process, benefits, cost, factors affecting commissioning & its cost, value of commissioning market survey and, two Thesis related to commissioning. All of the presented information are form (14) previous literature, studies, researches, books, articles and surveys.

1. The Beginning of Commissioning

Commissioning started in the U.S Navy in the late 1700's. New U.S ships and submarines were engaged in sea trials to determine that the ship is operating properly and to determine any malfunctions and corrected. In addition, commissioning prepares the crew and train it during this sea trails to increase the efficiency of operating these ships and submarines. The preparation time between christening- launching and commissioning may take as much as three years for a nuclear-powered aircraft carrier, or to as brief as twenty days for a World War II landing ship (Naval History and Heritage Command, 2019).

However, in the construction industry due to the growth in the construction projects and how new projects and buildings became complex because of the advance in the technology being used. Buildings commissioning was firstly introduced by public works in the Canadian project delivery system in 1977. Then in 1988, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) publishes HVAC Commissioning Guideline. In 1993, the first NCBC (National Conference on Building Commissioning) was held. The BcxA (Building Commissioning Association) was established in 1996 to help regulate and connect the commissioning industry, in 2004 BcxA launched certification program and in 2011 publishes Best Practices in Commissioning for New Construction. 2017 was NCBC 25th Anniversary hosted by BcxA in Utah (BcxA, 2018).

Moreover, testing and commissioning became essential in all mega projects around the world and project owners start to hire third-party commissioning companies to perform the testing and commissioning for their projects. A lot of these third-party companies are NEEP (National Environmental Balancing Bureau) certified companies which is one of the leading associations in this industry, NEEP has over 700 certified companies and over 1000 certified professionals and technicians around many countries in the world.

2. The Definition of Testing and Commissioning

2.1 Testing

According to Rumane (2011), Testing is checking and inspecting all works while construction is in progress. there are certain tests to be carried out by the contractor in the presence of the client and consultant, which are especially for electromechanical and conveying systems. Testing of these systems starts after the completion of installation of all works and by that time the facility has to be to connected to the permanent electrical power supply.

Inspections and testings are required to confirm the compliance of the equipment's and systems with drawings and specification of the project and manufactural. Inspections and testings are usually for static components, while on the other hand dynamic components such as machinery require testing and commissioning. Moreover, these tests are attended

by the contractors, third-party inspection authorities, manufactural or supplier, owner representatives and, the consultant. The tested systems in most projects are include but not limited to the following:

- HVAC system.
- Firefighting system.
- Water supply, plumbing, and public health system.
- Integrated automation system (building automation system).
- Electrical lighting and power system.
- Grounding (earthing) and lightning protection system.
- Emergency power supply system.
- Fire alarm system.
- Telephone system.
- Communication system
- Electronic security and access control system.
- Public address system.
- Conveying system.
- Electrically operated equipment.

2.2 Commissioning

According to Rumane (2011), Commissioning is the sequence of testing, adjusting, and balancing the facility system and bringing them into operation. The commissioning starts when construction and installation of works are complete. Commissioning is also attended by the contractors, third-party inspection authorities, manufactural or supplier, consultant, owner representatives, and the end user operation and maintenance personnel. Commissioning of construction project is a complex series of start-up operations and it may extend over many months before the handover, it requires a lot of planning and preparation work which begins before the construction is completed.

In addition, the National Conference on Building Commissioning has created a definition of Total Building Commissioning as follows:

“Systematic process of assuring by verification and documentation, from the design phase to a minimum of one year after construction, that all facility systems perform interactively in accordance with the design documentation and intent, and in accordance with the owner’s operational needs, including preparation of operation personnel” (U.S. General Services Administration, 2005).

3. Commissioning Types

According to Lindstrom & Schwartz (2014) They mentioned four primary types of commissioning as follows:

3.1 New Construction Commissioning

New construction commissioning is the most known and used type of commissioning. It is a process of verifying and documenting that a project or a facility and all of its systems and equipment’s are planned, designed, installed, tested, operated and, maintained as per the project specification and owner requirements. The new construction commissioning process begins from the predesign phase to the warranty period that is one year after the construction and handover. Also, it involves the training the end user operation and maintenance personnel.

3.2 Re-Commissioning

The re-commissioning or the ongoing commissioning is a commissioning process that is repeated after a project or facility is originally commissioned before. This type is highly preferable after long period of time is passed from the original commissioning time, and that is due to the decrease of the building systems and equipment's performance over the years. The re-commissioning can restore the efficiency of the building again.

3.3 Retro- Commissioning

The Retro- Commissioning is a commissioning process for existing buildings that has not been commissioned before. Building systems are tested to perform properly according to the current facility requirements. Low-cost or no-cost improvements such as energy saving measures or reliability increment are recommended, and then implemented and commissioned to ensure optimal performance of the facility.

3.4 Monitoring-Based Commissioning

Monitoring based commissioning is a commissioning type that involves the process of collecting, storing, analyzing and reporting data (collected through metering equipment) to identify and optimize actual energy performance and efficiency of a building. Monitoring based commissioning aims to resolve performance issues as they surface and continually refine facilities.

4. Testing and Commissioning Process

The commissioning of new buildings includes five phases each phase has key important activities, these phases and its description were made by ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers) in Guideline 0 – 2005 (Baechler, 2011).

4.1 Pre-Design Phase (Project Planning Phase)

In this phase the commissioning agent or company (third party) is selected along with the design team for the project. The commissioning company helps in in the development of the Owners Project Requirements (OPR). In addition, the commissioning roles and responsibilities are defined in this phase and the commissioning company starts developing the project commissioning plan.

4.2 Design Phase

In the design phase the commissioning plan is completed and updated, and the commissioning specifications are created along with the commissioning procedures. The design and its documents are reviewed for any comments by the commissioning company in reflect with the owner OPR.

4.3 Construction Phase

The construction phase is the phase that the commissioning company involves the most in the work. The commissioning plan is implemented, material submittals and TAB (Testing, Adjusting and Balancing) procedures are reviewed. The commissioning company evaluate the installation of equipment's by the pre-commissioning or pre-functional chick list. In addition, TAB works starts for all HVAC equipment's along with startup tests to verify problems and correct them, many meetings, site visits and inspections are held with the contractor and suppliers. Moreover, the commissioning project schedule is developing along with the commissioning documentation, O&M (Operation and Maintenance) manuals and training documentation. A detailed functional performance test plan is created for each system and equipment involved in the commissioning process.

4.4 Acceptance Phase

In this phase, the commissioning company start the functional and performance test of all the building mechanical, electrical and, low current equipment's & systems along with the TAB testing foe the HVAC system. All the tests are conducted by the contractor and the equipment or system supplier supervised by the consultant and commissioning company, witnessed by the client or client representative. Any issues or problems found during this period are corrected. In addition, the end user O&M personnel attend some of these tests for their comments and requirements regarding the operation and maintenance of the building.

Moreover, the training of the building operation and maintenance personnel usually occurs near the end of the acceptance phase or shortly after building occupancy. The training includes theoretical and practical parts based on the O&M manuals conducted by the supplier of each system and equipment in the building.

The acceptance phase in some projects may also include a trailer and demonstration period for not less than two weeks to operate the building in its full capacity with all systems integrated together to verify the functionality of the building. All tests are documented and singed by all parties and included later in the final commissioning report.

4.5 Post-Acceptance Phase (Project Occupancy Phase)

This phase is when the owner and end user occupy the building, and the building operation and maintenance start operating and maintaining the building and absorbing any day to day malfunctions or issues with the building systems and document it all as evidence for the commissioning company. In addition, this phase is intended to respond to the changes that may occur in the building or its systems over time.

Further, the commissioning company will be also involved in conducting seasonal performance testing that could not be performed previously such as extreme weather testing for the building cooling, heating or drainage system for example. All the results from the post-acceptance phase are added to the commissioning report, and the report will be finally submitted to the client (Energy Efficiency Factsheet, 2005).

5. Testing and Commissioning Benefits

Now a day the whole globe is moving toward energy saving through international & local regulations, standards, and, codes. One of the most beneficial benefits of commissioning is operational cost reduction by energy saving as figure (2.1) shows. Commissioning have also many benefits other than the financial aspect such as increasing the building and it O&M personnel performance.

According to APEGM, building commissioning guideline in (2002), it divides commissioning benefits into short-term and long-term benefits, the short-term benefits included the following:

- The establishment of good trained operations and maintenance staff empowered with comprehensive O&M manuals written by personnel responsible for the overall system design.
- Reduction in any potential costly shutdowns of main equipment's resulting from inadequate review and testing.
- The early identification of any issues prior to the occupancy or before warranty expiration, that results in a strong position for owners to have defects corrected by the parties responsible for them, on a timely basis.
- As for the long-term commissioning benefits the paper included are as the following:
- Reduction in energy consumption and operating costs over the life time of the building as a result of operation staff understanding the capabilities of the building systems and equipment's.
- Improving the liability of the building especially when the performance of the building systems can negatively impact on product quality or on the health and safety of building occupants.
- Improving the service life cycle of the facility equipment's.

According to Baechler (2011), they divided commissioning benefits into three categories (Construction cost savings, Ongoing energy savings and Non energy and "intangible" benefits).

5.1 Construction Cost Savings

Commissioning construction cost savings is resulted from less change orders and project delays. Identifying issues and problems early during the design review process will results in less post occupancy, corrective work or snag list work, and improved operation and reliability of e the equipment's.

In addition, When the commissioning starts during the pre-design or design phase of a new construction project, the deficiencies could be identified in very early stage instead of identifying them on site or during construction and this will be much less expensive to resolve them. Also, early design review by the commissioning agent can avoid problems such as oversized equipment and incorrect or incomplete sequences of operations.

5.2 Ongoing Energy Savings

The ongoing energy benefits is resulted from identifying design and site issues that lead to inefficient system operation and wasted energy. When deficiencies even small ones are not identified, it could result for these deficiencies to be undetected for years negatively affecting the building energy use, equipment reliability and, occupant comfort.

A study included 643 buildings in U.S.A pointed that resolving deficiencies that is found during the commissioning process resulted in 16 % energy savings in existing buildings and 13 % in new constructed buildings, with payback period of 1.1 years and 4.2 years, respectively.

Another more comprehensive study found the value of energy savings from commissioning could be as shown in figure (1). Moreover, proper commissioning can increase these savings over time. Studies found that when the commissioning process includes staff training, installation metering devices and feedback systems such as BMS (Building Management System), the improvements in system performance can be for years after the commissioning.

Savings from Commissioning		
Description	Range of Values	Expected Annual Savings for a Theoretical 100,000 sq. ft. Building
Value of Energy Savings	$0.02 - $0.19/sq. ft.	$2,000 - $19,000
Value of Non-Energy Savings	$0.23 - $6.96/sq. ft.	$23,000 - $696,000

Figure (1): Savings from commissioning

5.3 Non-Energy and "Intangible" Benefits

A report by the Lawrence Berkeley National Laboratory indicates that the non- energy benefits from commissioning are the primary motivator for buildings commissioning. The benefits include, increased equipment performance and improved indoor air quality, lighting, temperature control and, building pressure control that will result in the increase of the occupant comfort, health and, productivity as figure (2) shows. All of these non-energy commissioning benefits are accomplished by implementing the following:

- Good air ventilation.
- Proper air filtration.
- Functionality of lighting controls.
- Sufficient light levels as specified in design documents.
- Calibration and functionality of temperature sensors.
- Calibration and functionality pressure and flowrate sensors.

Figure (2): The non-energy benefits from commissioning

6. Commissioning Cost

The cost of commissioning dependents on many factors such as building size, building systems complexity and, if the project commissioning is for a new construction project or for a building renovation (existing building commissioning). The cost of commissioning for new building ranges from 0.5–1.5% of total construction cost. While on the other hand, existing building commissioning that has never been commissioned can range from 3–5% of total operating cost. Figure (3) shows the cost of commissioning for new construction projects (Los Alamos National Laboratory Sustainable Design Guide, Ch:9 Commissioning the Building, 2002).

Costs of Commissioning, New Construction

Commissioning Scope	*Estimated Cost*
Entire building (HVAC, Controls, Electrical, Mechanical)	0.5–1.5% of total construction cost
HVAC and Automated Control System	1.5–2.5% of mechanical system cost
Electrical Systems	1.0–1.5% of electrical system cost
Energy Efficiency Measures	$0.23–0.28 per square foot

Source: Building Commissioning Guide. Version 2.2. 1998. DOE/GSA.

Figure (3): Cost of commissioning for new commissioning

According to Mills et al. (2004), the study analyzes 224 buildings in the United States of which 27 % of them were for new construction commissioning that represent $1.5 billion of total construction cost. The study found that the median commissioning costs were $1.00/ft2 (0.6 percent of total construction costs), yielding a median payback time of 4.8 years (excluding quantified non-energy impacts) for new construction commissioning. Figure (4) shows the study commissioning cost, payback time and energy savings.

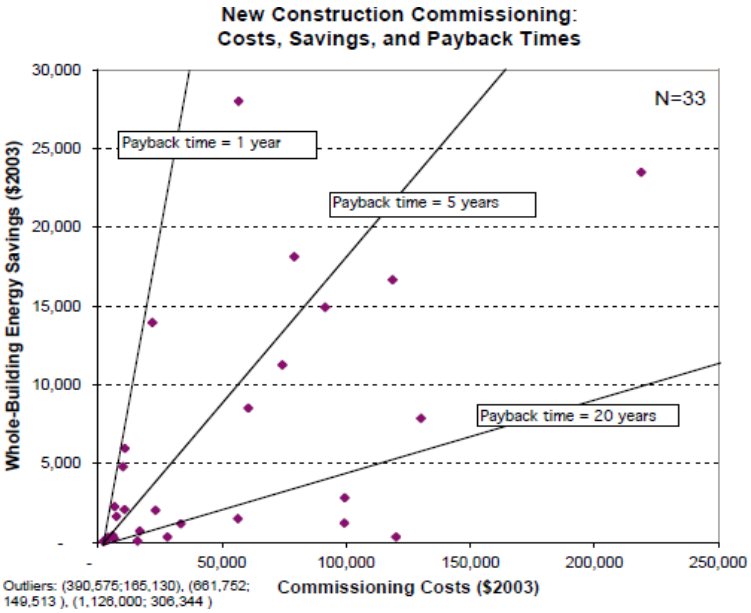

Figure (4): Commissioning cost, payback time and energy savings

7. Factors Affecting Commissioning and its Cost

According to the Kubba (2017) commissioning costs differ from one project to another and that differences depends on many factors like projects size, complexity and the scope of commissioning. This is why commissioning cost is always represented as a range in all researches and guide lines. However, Commissioning and its cost are affected by many factors that includes the following:

- The building size and type.
- The number and type of the systems to be commissioned.
- The starting time of commissioning (e.g., during design, construction or postconstruction).
- New construction of building renovation.
- Required deliverables (design intent document, commissioning plan, commissioning specification, O&M manuals, training plans, final report…etc.).
- Commissioning process protocol and if it includes documenting and witnessing all equipment prestart-up, start-up, per functional test procedures, functional test procedures…etc.).
- The availability of measuring tools such as (sensors, meters, thermometer… etc.).
- Costs allocation (e.g., does it include commissioning consultant fees, increased contractor bids, increased design fees… etc.).
- Degree to which the commissioning company actively performs testing or not, as opposed to passively observing testing.

8. Value of Commissioning Market Survey

According to a market survey of the value of commissioning funded by the Building Commissioning Association (BcxA) (2018). The purpose of the Survey, is to provide a feedback on market influences, reasons of procuring commissioning services, incorporation of established commissioning practices and, the effectiveness of commissioning. The survey was sent on two rounds to BcxA members and relevant stakeholders in 2017 and 2018. A total of 120 subject matter experts responded to this the market survey On NCCx (New construction commissioning), the survey highlighted factors influencing the commissioning marketplace and ask respondents to rate the importance of each factor influencing the NCCx marketplace. The survey rating was based on a scale of 1-4, the highest rated factor resulted was Owner Awareness having the highest impact on market. Second highest was Building Codes, and the other factors ratings are as figure (5).

Figure (5): Factors influencing the commissioning marketplace

As for the profitability and market growth of the commissioning industry. The survey shows that 50% of respondents indicated that their profits are remaining the same. While 35 % agreed – or strongly agreed that their businesses are increasingly profitable. In addition, 4 % believed that their company will commission more square footage compare to 2017 over the next five years.

Moreover, the survey indicates that about 25% of the total project issues were discovered during design phase. Given the high value and low cost for addressing project issues early during design. However, based on the survey there was a lack of effectiveness for commissioning firms commenting in the review and equipment selection process. The survey report presented some possible reasons for this lack of effectiveness as the following:

- The format of documenting the comments.
- Lack of communication between the design team and commissioning providers.
- Low design team budget.
- Misconstrued context of comments.
- Unintended interpretation by the design team.
- Design teams underestimating the value of commissioning comments.
- Lack of owner support in the review process.

Furthermore, regarding the satisfaction of the quality of the project facility training personnel. Responses indicated that the satisfaction of the training from the respondent's perspective is low. Only 27 % claimed to be "satisfied" or "very satisfied" with the quality of the training, while 35 % claimed to be "unsatisfied" or "very unsatisfied", as figure (6) shows. The survey report presented a minimum of six items to be covered for a proper facility personnel training as followed:

- Conducting systems and equipment's overview including walk-throughs.
- Describe and demonstrate systems operation.
- Discuss the content and layouts of the O&M manuals.
- Pointing safety issues, alarms and common troubleshooting.
- Cover service, maintenance, and preventive maintenance of all systems components and devices.
- Provide recommendations for maintaining high efficiency of the facility.

Factor	Impact
Owner Awareness	3.8
Building Codes	3.7
Voluntary Rating Programs	3.6
Public Policies	3.5
Utility Programs	3.1
Trade Associations	2.8

Figure (6): The satisfaction of the quality of the project facility training personnel

In addition, the survey report presented the top reasons that project owners procure NCCx Services, and they are (79% ensure system performance, 65% comply with LEED or sustainability rating systems, 55% smoother turnover, 53% ensure thermal comfort and 50% train building operators). The reasons were reported over 50% of the time. While factors such as building energy savings, improved indoor air quality and occupant productivity were not as high as the previous mentioned reasons that encourage owners to procure NCCx services. Yet, owners reported that they have ongoing improvements from NCCx after construction is completed that includes the following:

- 95% better thermal comfort.
- 87% improved O&M practices
- 87% improved staff training.
- 72% improved indoor air quality.
- 69% improved equipment life cycle.
- 56% less warranty calls and change orders.
- 90% issues identified and corrected earlier.
- 77% improvements to system design.

Finally, the report summaries the observations obtained from the NCCx survey results section. Firstly, design phase commissioning services are included in almost 60 % of NCCx projects. Secondly, design phase commissioning review comments are incorporated in contract documents over 50 % of the time. Thirdly, design phase issues consist about 25 % of all NCCx issues.

9. Existing Building Commissioning Impact

According to the Existing Building Commissioning: Exploration of Use and Impact Thesis by Hallowell (2018). The thesis objective is to provide estimated quantification of the implementing and the impact of existing building commissioning, along with general building commissioning, in the terms of energy savings and total cost based on 198 commissioning providers members of the BcxA (Building Commissioning Association) and their estimated annual revenue values.

The findings and calculations performed in the study, generate an approximate value that is useful to understand the magnitude of existing building commissioning impacts for the sample, as well as the larger building commissioning impacts. The main estimated calculations with the percentage of existing building commissioning to total building commissioning are as shown in figure (7):

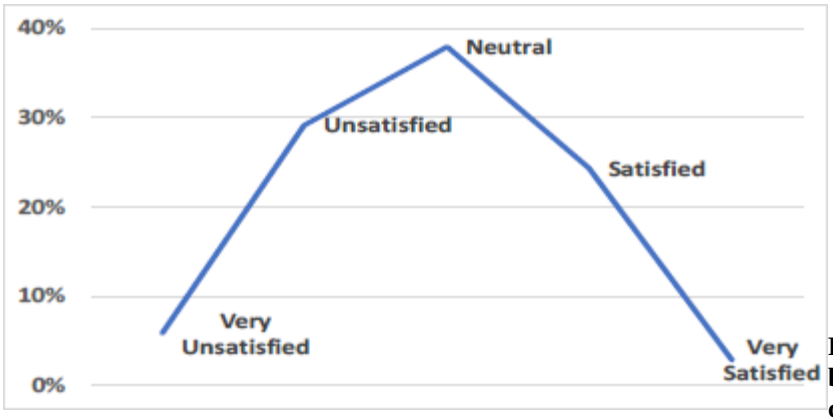

Figure (7): Percentage of existing building to total building commissioning

The values could underestimate the true implementation and impact of the U.S. commissioning market. However, the study adequately approximates the scale of revenue, cost and energy savings within the sample. The values suggest a sizeable impact from the

	Existing Building Commissioning	Total Commissioning	Percent EBCx
Estimated Annual Revenue	$270,000,000/year	$1,800,000,000/year	15%
Estimated Annual Floor Area Commissioned	780,000,000 ft^2/year	2,000,000,000 ft^2/year	39%
Estimated Annual Cost Savings	$290,000,000/year	$540,000,000/year	54%
Estimated Annual Energy Savings	22,000,000,000 kBtu/year	50,000,000,000 kBtu/year	44%

selection of commissioning firms in terms of general scale. Addition further updating and refining the methodology, especially regarding to the commissioning constants, revenue percentages, and the included providers may lead to better results.

10. Building Commissioning from The Contractor's Perspective

According to the Building Commissioning from The Contractor's Perspective Thesis by Dorset (2008). The study main objective is to gather and analyze contractor's perceptions regarding commissioning process in order to assess what changes need to be made. The study is based on a survey that was used to measure the awareness of contractors, and provide insight of the changes that need to be done for the contractors to keep up with the rapidly evolving commissioning industry. The study survey results showed that many of the contractors only had the basic understanding of the commissioning process.

The study collected 31 completed surveys from the Fall of 2007 and the Spring of 2008. The respondents were from companies specializing in all types of construction with varying sizes and annual volumes, almost two-thirds of the respondents were project managers, followed by small number of estimators and upper management employees. The average years of experience was approximately eight years. Some of the results from the building commissioning survey were as followed:

- 58% of the respondents claimed to be currently working on a project that was being commissioned.
- The average of the projects that involved commissioning were 49% of the total respondents projects.
- The average amount of the LEED projects that involved commissioning third party agent was 20%.
- The average personal knowledge of the commissioning process was Approximately "3" or about average.

- The average company's level of knowledge of the commissioning process is, Approximately "4" or above average.
- The average amount of how much beneficial the respondents think that commissioning process is, in helping to meet the owner's expectation is, Approximately "4" or above average.
- The average amount of the effectiveness the respondents think that commissioning can reduce the number of call-backs after a project is completed is, Approximately "4" or above average.
- The average amount of the economic standpoint the respondents think about the value of commissioning in comparison to cost is, Approximately "3.5" or between average and above average
- The average amount of the effectiveness the respondents think about the third- party commissioning agent in terms of streamlining the commissioning process is, Approximately "3.5" or between average and above average.

Finlay, as mentioned before the study survey highlights that there is likely a lack of awareness and understanding of the commissioning process by contractors and construction managers. The reason of this lack of awareness is due to two contributing factors. First reason, contracting companies has too much reliance on the mechanical engineer, commissioning agents and subcontractors during the commissioning process. The second reason, is that many contracting companies do not focus enough resources exposing their employees to the commissioning process. With no increase in the commissioning awareness and training programs for contractor's employees, there will still be a continues gap of knowledge between contractors and other project team members who are involved in the commissioning process. An increase in the number of in-house contractor training programs could close up this gap.

STUDY METHODOLOGY:

After identifying the study problem and determining the study scope and objective in the first section. In addition to reviewing the background information of relevant topics of previous literature, studies, researches, books and surveys in the second section. This section presents the methodology that was used in this study by the researcher in the implementation of the current research study.

1. Methodology

The conducted methodology that was used to achieve the study objectives, was done by making a questionnaire form to collect the required data in order to identify the most factors affecting testing and commissioning in the construction projects. Thus, determine and discuss some of the causes of these factor, possible solutions and, what are the consequences of having these factors affecting the testing and commissioning in construction projects, that will be done in the Results and Analyze section.

After that a conclusion and recommendations will be given based on the analyzed collected data to minimize the effect of those factors and to improve testing and commissioning in the construction projects in general.

Furthermore, the selected factors were identified by the researcher as a testing and commissioning engineer, previous literature reviews and, specialized experienced testing and commissioning engineers. The questionnaire was distributed among (engineers, supervisors, managers and, directors), in the privet and governmental sectors of construction projects and operated facilities in the Kingdom of Saudi Arabia. The distribution of the questionnaire was done through the platforms of social media using WhatsApp and LinkedIn applications.

2. Questionnaire Form

The questionnaire form was made using Google Forms, as it's an easy and effective platform to make such type of questionnaires. In addition to the easy accessibility for the respondents especially that it does need any requirements that the respondents have to do except answering the form. The form was divided into two parts, general part and the affecting factors part as Appendix (A) shows the used distributed form.

2.1 Questionnaire Form First Part

The first part, is for general questions to understand the background and how relative the respondent is to the study topic. The first part questions were as shown in table (1):

Table (1): Questionnaire form – first part

NO.	Question
1	Is your current job related to Testing and Commissioning?
2	Select your organization Type.
3	Job title.
4	Years of Experience.

2.2 Questionnaire Form Second Part

The second part of the form, is where the respondent is asked to rate the presented factors that affect testing and commissioning from one to five where ("1" means no effect, "2" means low effect,"3" means average effect, "4" means high effect and, "5" means very high effect. Moreover, this part also included optional request for the respondents to write

their names and organization names, in addition to any suggestions for the study. The selected factors for the study were 25 factors as shown in table (2):

Table (2): Questionnaire form – second part

NO.	Factor
1	Project Specification.
2	The procedure of the Testing and Commissioning in the Project Specification.
3	The procedure of the Testing & Commissioning of equipment's in the T&C Method Statement.
4	Third party qualification.
5	The duration of the Testing and Commissioning period.
6	The parties attending the Testing and Commissioning.
7	Client influence in the Testing and Commissioning.
8	Trial Demonstration procedure and duration.
9	Criteria of the snag list.
10	Material's and equipment's (storage conditions, delivery and handling).
11	Calibration and Balancing of equipment's.
12	Pre-commissioning.
13	Project Location.
14	Equipment's installation and inspection.
15	Factory Acceptance Test (FAT).
16	Equipment's selection and approval.
17	Accessibility of the equipment's in the test.
18	Test validity period.
19	Installation snag list.
20	Testing and Commissioning cost (budget).
21	Quality and calibration of the testing measuring devices.
22	Project magnitude.
23	Implemented project standards.
24	Type and quantities of equipment's and systems to be tested.
25	The implantation of caretaker maintenance before the Testing, Commissioning and Handover.

3. Data collection:

Based on the study methodology, all the selected factors will be rated using the questionnaire form. The questionnaire will analyze the factors to identify the most affecting ones from each respondent point of view. Each respondent answers and any suggestions will be collected directly online through the Google forms webpage, and downloaded into an Excel sheet for further analysis in the Results Analysis section.

$$\bar{x} = \frac{\sum x_i}{n} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

Figure (7): Mean equation

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

Figure (8): Standard deviation equation

$$\% = \frac{\sum_{i=1}^{n} \chi_i}{\sum(\sum_{i=1}^{n} \chi_i)}$$

Figure (9): Percentage equation

RESULT ANALYSIS:

This section presents the results of the questionnaire, by ranking all the factors affecting the testing and commissioning to identify and show the importance of each factor, in order to determine the most affecting factors in the private and governmental construction projects. Also, the questionnaire answers are built from the different perspectives of the respondents experienced working as (Clients, Consultants, Contractors, Third party companies, operators and, suppliers), not only in construction projects, but also in operated facilities.

1. Questionnaire Results

The questionnaire collected 135 complete responses in the duration of almost two weeks, through respondents in Saudi Arabia with variation of different (nationalities, organizations, level of experiences and, job titles), three examples of the responses are shown in Appendix (B). The respondents were also from different types of construction project such as (transportation projects, residential projects, hospitality projects and, oil & gas projects). Moreover, some of the respondents were in the operation and maintenance industry for facilities such as (power plants, petrochemical plants and, train stations), however some of them currently related or have been experienced with the testing and commissioning.

Furthermore, the questionnaires used a five-point ranking technique, to rate the effect of the questionnaires factors. The ranking of the factors is from the highest to lowest effect that depends on the highest mean. The highest mean value of all factors will be ranked as number 1; the following highest value gives number 2, until it reaches the lowest value. This study primarily depends on means and standard deviations. The mean is calculated using the equation in figure (7), the standard deviation is calculated using the equation in figure (8) and, the percentage is calculated using the equation in figure (9).

1.1 Questionnaire Part One Results

The first part of the questionnaire, is to understand the background and how relative the respondent is to the study topic. The result of the number of respondents current jobs relation to testing and commissioning or not, are as figure (4.4) shows and as follows:

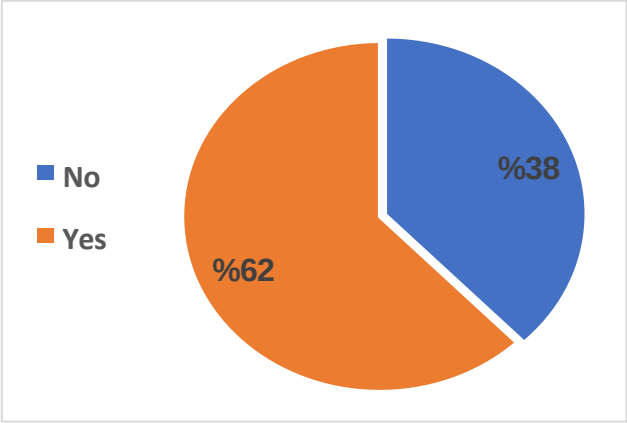

Figure (10): Respondents relation to testing and commissioning

84 of the respondents responded that their current jobs are related to testing and commissioning with 62%. While 51 responded that their current jobs are not related with 38%. However, these numbers are only for current jobs and that does not mean that the 38% of the respondents do not have any experience or relation with testing and commissioning in the past.

The result of the respondents current working organizations is as figure (4.5) shows, and as follows:

- 33 of the respondents were working as Operators with 24%.
- 21 of the respondents were working as Contractor with 16%.
- 53 of the respondents were working as Client with 39%.
- 6 of the respondents were working as Supplier with 4%.
- 5 of the respondents were working as Third Party with 4%.
- 17 of the respondents were working as Consultant with 13%.

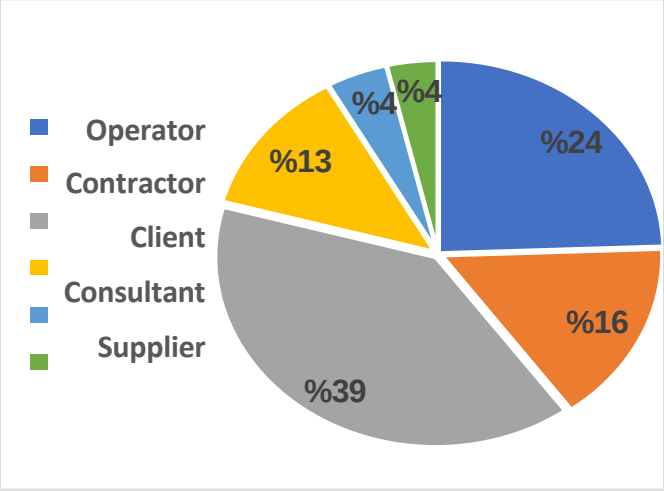

Figure (11): Respondents working organization

The result of the respondents current working job title is as figure (12) shows, and as follows:

- 52 of the respondents job titles were as Engineer with 38%.
- 48 of the respondents job titles were as Manager with 36%.
- 25 of the respondents job titles were as Section Head with 19%.
- 10 of the respondents job titles were as Director with 7%.

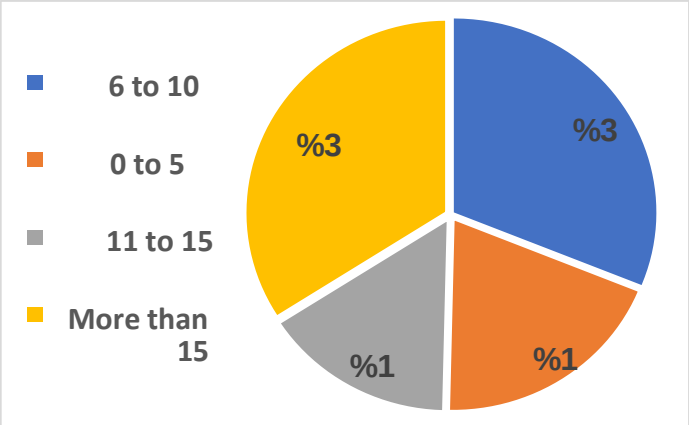

Figure (12): Respondents working experience

1.2 Questionnaire Part Two Results

The second part of the Questionnaire, is where the respondent was asked to rate each of the 25 factors that affect testing and commissioning from one to five as explained previously. After analyzing part two results, the (ranking, standard division, mean and, percentage) of each of the 25 factors are as table (3) shows.

Table (3): Questionnaire results and analyzes

NO.	Factor	Degree of effect					%	Mean	Standard division	Rank
		Very high effect	High effect	Average effect	Low effect	No effect				
1	Project Specification.	92	29	10	1	3	4.63	4.526	0.845	1
2	The procedure of the Testing and Commissioning in the Project Specification.	75	40	19	1	0	4.50	4.400	0.755	2
3	The procedure of the Testing & Commissioning of equipment's in the T&C Method Statement.	69	47	14	5	0	4.43	4.333	0.810	3
4	Third party qualification.	63	43	23	5	1	4.30	4.200	0.904	6
5	The duration of the Testing and Commissioning period.	28	53	46	6	2	3.82	3.733	0.891	19
6	The parties attending the Testing and Commissioning.	33	56	39	6	1	3.93	3.844	0.871	14
7	Client influence in the Testing and Commissioning.	40	39	29	16	11	3.68	3.600	1.253	21
8	Trial Demonstration procedure and duration.	30	49	48	7	1	3.83	3.741	0.889	18
9	Criteria of the snag list.	25	30	48	31	1	3.43	3.348	1.053	25
10	Material's and equipment's (storage conditions, delivery and handling).	36	50	33	12	4	3.84	3.756	1.040	17

11	Calibration and Balancing of equipment's.	60	46	23	4	2	4.27	4.170	0.919	6
12	Pre-commissioning.	33	64	27	10	1	3.96	3.874	0.893	13
13	Project Location.	37	36	35	18	9	3.63	3.548	1.214	22
14	Equipment's installation and inspection.	52	49	27	6	1	4.17	4.074	0.911	8
15	Factory Acceptance Test (FAT).	58	47	16	10	4	4.17	4.074	1.055	8
16	Equipment's selection and approval.	49	52	22	11	1	4.11	4.015	0.962	10
17	Accessibility of the equipment's in the test.	34	50	42	8	1	3.89	3.800	0.913	16
18	Test validity period.	32	49	40	11	3	3.80	3.711	0.992	20
19	Installation snag list.	23	40	51	19	2	3.55	3.467	0.983	24
20	Testing and Commissioning cost (budget).	29	39	44	16	7	3.58	3.496	1.112	23
21	Quality and calibration of the testing measuring devices.	63	46	21	3	2	4.32	4.222	0.895	4
22	Project magnitude.	52	38	29	9	7	3.97	3.881	1.153	12
23	Implemented project standards.	65	44	18	6	2	4.31	4.215	0.941	5
24	Type and quantities of equipment's and systems to be tested.	39	46	41	5	4	3.91	3.822	0.992	15
25	The implantation of caretaker maintenance before the Testing, Commissioning and Handover.	39	51	39	4	2	3.99	3.896	0.908	11

1.3 Questionnaire Respondents Suggestions

The questionnaire only received a few suggestions by the respondents, and some of the respondents suggestions agreed with the factors already mention in the questionnaire such as the selection and installation of equipment's. In addition, one of the respondent highlighted that the testing and commissioning process is to replicate or exceed the operational conditions of the facility in a short time frame to insure that the facility equipment's and systems are meeting design, specification and, requirements. Also, to study the effects of fatigue, wear and, tear that could face that equipment's. Other suggestions included were as the following:

- The quality of the contractor commissioning team.
- QC efficiency during testing and commissioning.
- The availability of the equipment documentation by the manufactural and contractor during tests.
- The influence of climate conditions.
- The consultant importance as it's his responsibility to lead the test, approve the testing method statement and, accept the results.

2. Discussing the Highest 10 Effecting Factors, Possible Solutions and Consequences

The two highest factors are both related to the project requirements and specifications documentation, which they are "Project Specification" and "The procedure of the Testing and Commissioning in the Project Specification". Both of these factors will affect the testing and commissioning even before it begins. The consequences of the two factors will be very high as both of them are the foundation of the testing and commissioning procedures and requirements in the project. This is possibly why both of them are the highest and in the same time they have the lowest standard deviation in accordance to the respondents results. Without these two factors clearly mentioned in details in the project specification, the contractor could provide a very low-quality work for the testing and commissioning as he will not have that much obligation. In addition, that the client will have no strong leverage on the contractor. The possible solution, is that clients and project designers have to mention the testing and commission general requirements in the general project specification document, and to describe its procedures in a separate specified part of the specification.

The third highest factor, is "The procedure of the Testing & Commissioning of equipment's in the T&C Method Statement". This factor will also have a very high impact on testing and commissioning, as it describes the steps of each test in details and contains the pre-commissioning and commissioning check lists for each equipment and system in the project. The consequences of not having this method statement or having it in a weak manner, will result for not testing or covering all the equipment or system components and functions. The best possible solution for this issue, is to establish all the testing and commissioning method statements by the third- party commissioning company to ensure the coverage of testing all the equipment and systems aspects, as they are specialist in commissioning.

The fourth highest factor, is "Quality and calibration of the testing measuring devices". This factor may affect the testing and commissioning results without even knowing that, and that's because the measurements are not verified to be correct or no. That's why all the measuring devices have to be from a well-known brand and, to be calibrated in a yearly base to ensure its accuracy. Also, this condition has to be mention in the testing and commissioning procedures in the project specification, to obligate the contractor and third-party commissioning company by that.

The fifth highest factor, is "Implemented project standards". This factor could be considered as the foundation of the project along with the project specification as the project is built and designed in accordance to them. It is important to relate the testing and commissioning to the international standards such as (ASHRE, NFBA, SMACNA. etc...), as well as complying with local codes and regulations to ensure that the project will not be rejected by local entities such as the civil defense or the municipality.

The sixth highest factor, is "Third party qualification". It is very important when choosing a third-party commissioning company, to request for their (qualifications, previous projects, certificates etc.…), as most of the commissioning work is done by them, and having a non or low qualified third-party commissioning company will lower the quality of the testing and commissioning work.

The seventh highest factor, is "Calibration and balancing of equipment's". This factor is considered as one of the important parts of the commissioning process, as testing the equipment's functions, performance and, sequence of work only is not enough to meet the project requirement parameters such as pressures and flow rates especially for the HVAC system. To do that all the equipment's related valves, dampers and, rotating components has to be balanced and calibrated to meet the designed parameters and to optimize the facility performance and efficiency.

The eighth highest factors, are two factors "Equipment's installation and inspection" and "Factory Acceptance Test (FAT)", as they had the exact same mean. The "Equipment's installation and inspection" is actually in the construction phase. However, if the equipment's were not installed and inspected properly, it will not ever perform as required. To prevent that, the inspection of the installation must be verified also in the pre-commissioning phase. As for the "Factory Acceptance Test (FAT)", it's very crucial to have it for all the project equipment's especially for the main and important ones such as (generators, AHU's, chillers, transformers. etc...), as the Factory Acceptance Test is done by the manufactural in the factory with special tests that cannot be done on site. To ensure that all the main and important equipment's has to have Factory Acceptance Test (FAT) certificate along with the test reports and, all the typical equipment's that have large quantities should have at least one Factory Acceptance Test (FAT) certificate for each type.

The tenth highest factor, is "Equipment's selection and approval". All the equipment's has to be selected in accordance with load and calculations that the facility needs, some of these load calculations are done by the designer and the other part is done by the contractor or supplier. In the part that is not done by the designer all calculations have to be reviewed and approved by the consultant and the selection of all the equipment's has to be based on the load calculation. Otherwise the equipment's will not meet the design requirements no matter if the testing, commissioning and balancing was done or not.

Further, the ranked factor number 21 "Client influence in the Testing and Commissioning", has the highest standard deviation with 1.253. Which means that the respondents decisions were conflicted for some reason regarding this factor. However, in my opinion and as the literature review of the study presents in the "Market Survey of the value of commissioning funded by the Building Commissioning Association (BcxA) (2018)", that "owner awareness" had the highest impact on influencing the commissioning marketplace. I think that client or owner influence and awareness is one of the most effecting factors on testing and commissioning. As the owner awareness will lead to requesting a very strict testing and commissioning procedures and requirements in the project specification and, choosing the best qualified third-party commissioning company to ensure the quality and performance of his project. In addition, the influence of the client and the continues follow up of the testing and commissioning progress from the beginning to the handover will maximize the quality and results of testing and commissioning work.

CONCLUSION AND RECOMMENDATION

This section will present the conclusion and recommendation of the study, in addition to the study limitations and possible ideas for future researches. Also, the section includes a summary of study and its findings.

1. Conclusion

The study results were based on a questionnaire that contains 25 factors affecting the testing and commissioning. The factors covered many aspects of the testing and commissioning that could have affected before and during the testing and commissioning phase. The highest mean factor was "Project Specification" with a mean of 4.526, as the project specification and its design are the foundation of any project. Thus, the project specification is the foundation of the testing and commissioning and, how much the project specification is including and describing testing and commissioning general requirements and procedures how much it will affect it and increase or decrees its impact and final results on the project.

On the other hand, the lowest mean factor was "Criteria of the snag list" with a mean of 3.348. Yet, if the criteria of the snag list were not described on project specification or at least clearly agreed between all parties, it could have a significant impact on the testing and commissioning final results and operation of the facility. As if it not was described or agreed, then some or even a lot of the equipment's and systems functions or options might be considered as a snag, which could decrease the facility efficiency and the ability to fully controlling it.

Moreover, regardless of the ranking of the factors. It seems that all the factors have a significant impact on testing and commissioning, as the minimum mean for all the 25 factors is "3.348" and the overall mean is "3.91", which are consider relatively high. In addition, all the factors were identified by the researcher as a testing and commissioning engineer, previous literature reviews and, specialized experienced testing and commissioning engineers.

Finally, as mentioned in the literature review testing and commissioning has a lot of benefits for the short-term and long-term, that includes construction cost savings, ongoing energy savings and, non-energy "Intangible" benefits. And the cost of the testing and commissioning will be repaid in a few years from the energy savings alone. However, on the other hand the consequences of low-quality testing and commissioning, will affect the operation and performance of the facility equipment's and systems and will increase the maintenance and energy costs, as well as decreasing the life time of the facility equipment's and systems. This will not only impact the performance of facility alone, as the consequences will far extent to the occupant safety comfort, health and, productivity from having low quality temperature control, lighting and, indoor water & air quality.

2. Recommendation

- As mentioned before in the study problem statement. Testing and commissioning is a very important phase of projects life cycle. However, the problem is the fully and correct implementation of it, in addition to the existing or weak requirements of small to medium size projects testing and commissioning. Thus, the following are some recommendations for testing & commissioning and its effecting factors:
- All small to mega construction projects should have a testing and commissioning phase in its life cycle in proportion with the project size and cost, to ensure equipment's and systems are meeting the design requirements and specifications, plus the many previously mentioned benefits.
- All the testing and commissioning activities have to be done by a qualified third-party commissioning company, with the attendance of the project (contractor, consultant, supplier and, client representative) in addition to the end user O&M representative in the final commissioning phase.
- Testing and commissioning general requirements and procedures have to be mentioned and described in the project specification in accordance to the international standards, local codes and regulations. Also, each equipment or system to be commissioned have to be described in details by the commissioning third party company in the testing and commissioning method statement, and to be approved by the consultant.
- Testing and commissioning work should start in an early phase, as it's mentioned in the literature review (2.5 Testing and Commissioning Process). As in the pre-design and design phases the commissioning plan, specifications and procedures are done in those two phases. Also, the design is reviewed for any comments by the commissioning third-party company. All of that is to avoid any conflicts, delays or technical issues during construction and commissioning.
- All the project equipment's and systems have to tested and commissioned, and not only focusing on main ones. Those systems are mentioned but not limited to the (2.3 The Definition of Testing and Commissioning) in the literature review. Moreover, the testing could even include some architectural works such as (roofs, façade, sliding doors, roller shutters, fire curtains. etc.…).
- The final testing and commissioning period (The acceptance phase) should start in the perfect time, to allow for its process to be fully implemented without any interruptions and to allow for any rectification for technical issues or sometimes even design errors.

3. Future Research:

The factors affecting testing and commissioning are not comprehensively and widely researched in an academic perspective or in terms of researches and, that's was one of this study limitations as mentioned before. Thus, a more comprehensive researches should be done with more identified factors that affect testing and commissioning for construction projects in general and, for medium to small size construction projects in specific as most construction projects are medium to small size.

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