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The Impact of Enhanced Commissioning Process on AEC Professionals - A Case Study of LEED New Construction in Egypt

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Abstract

In this study, the authors explore the impact of the enhanced commissioning process required by LEED certification on the Architecture, Engineering and Construction (AEC) professionals through a case study of a (LEED) New Construction in New Cairo, Egypt. While research has consistently shown the positive impact of green-rated buildings on building occupants, little research discusses the impact of green building rating on AEC professionals. Observation, document analysis, and interview of AEC professionals were used throughout the course of design and construction to identify the impact of the enhanced commissioning process on the quality of Project delivery and experience of AEC professionals. All technical and managerial issues of the entire enhanced commissioning process were recorded and thoroughly analyzed. As a result, a comprehensive comparison between mainstream projects and the current LEED-certified building is established. The study introduces a novel insight on green building design and construction practice as a potential culture of quality for the building industry in developing countries.

Keywords: building commissioning, green building, quality, green rating systems, construction professionals

1. Introduction

"As global warming has become a growing concern in the last decade, Middle East and North Africa region has adopted energy efficiency (EE) policies and measures across several consuming sectors." (Bampou, 2016). In Egypt, the whole population is still living on 5% of country's land, this 5% isn't expected to provide a sustainable living for this population anymore (Cattane, 2011), therefore integrative collaboration towards sustainable development is no longer optional. Green buildings are environmentally significant as they enhance the indoor environment, and minimize the impact on the outdoor environment (EPA, 2016; Mansour & Radford, 2016). Green rated buildings are structures designed and constructed according to the requirements and specifications set by one of the available green building rating systems. The purpose of the rating is to incorporate the principles of sustainability throughout the life cycle of these structures; hence, green-rated buildings encompass benchmarked performance and provide verified and documented quality from Pre-design to the Operation and Maintenance stages. This anticipated quality and higher performance are keys for spreading the culture of sustainability that could lead to global recognition of the benefits of having green-rated buildings.

1.1 Background

In Egypt, the construction industry is growing at a rapid rate due to various reasons, the population growth is one of the biggest motivators; Egypt's population is currently 99 million, making its rank as the 14th in the list of countries by population, and is expected to reach between 150 and 180 million inhabitants by 2050 (Worldometers, 2017), the growth of population is also a source of available and inexpensive manpower. Another reason behind the construction growth is the high demand for real estate investment, which reached $5.3 BN in 2014/15, contributing around 5% to GDP (Cityscape, 2016). As a step towards sustainable development in the country, Egypt established the Egyptian Green Building Council in 2009, and immediately developed a national Green Building Rating System, Green Pyramid Rating System (Egypt-GBC, 2010). Additionally, the Egypt-GBC proposed significant incentives for buildings to get certified, incentives included: "Access to preferred and prime locations when selecting the project's sites, governmental Financial Assistance, and Utility

Concessions (Egypt-GBC, 2010). However, clients and market conditions catalyze spreading of innovation in the architecture, engineering and construction (AEC) industries (Mollaoglu, Chergia, Ergen, & Syal, 2016), clients and market conditions are still not fully geared towards the green trend in Egypt. Also, due to the current economic and political reforms in the country green building rating is still a recent emerging practice in Egypt. The local green building rating GPRS has never been applied on new construction – yet, 25 LEED buildings are currently registered in Egypt, 18 of them including the building shown in this study are already awarded; detailed as 1 platinum, 7 Gold, and 10 Silver projects (USGBC, 2018).

1.2 Literature Review

A survey of the literature reveals little prior contributions on comparing a commissioned with non-commissioned buildings under LEED projects in terms of their impact on project teams; additionally, no published work did conduct such a comparison in the cultural context of developing countries. However, there is some previous work that compared the applicability of LEED in three developing countries; India, Abu Dhabi, and Turkey, with focus on the Energy and Atmosphere (EA) credits category (Komurlu, Arditi, & Gurgun, 2014), but the study didn't discuss the applicability of building commissioning, although it is an EA prerequisite.

Additional literature by (Yu, Gero, & Gu, 2015) & (Perišić, Štorga, & Gero, 2019) did comprehensively discuss the behavior of architectural design professionals. Their research form a significant foundation to future similar research which may further discuss the impact of enhanced commissioning on practitioners' behavior and cognitive activity during the building process.

1.3 Aim and Objectives

In this article the authors analyze the outcomes of the enhanced commissioning process of one of these LEED buildings from the quality perspective, the objective is to identify the impact of the LEED certification on the quality of construction and behavior of building professionals.

2. Enhanced Commissioning, an Overview

Building Commissioning (Cx) is "a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria." (ASHRAE, 2005). It is also defined as: "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" (Fee, 2016). Commissioning is the most economic strategy for saving energy and ensures that building is operating according to intended targeted performance (Mills, 2011). Cx definitions imply objectives similar to the quality assurance definitions set by the International Organization for Standardization ISO 9001. ISO defines Quality as "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs" (FAO, 2017), and defines quality assurance as: "the assembly of all planned and systematic actions necessary to provide adequate confidence that a product, process, or service will satisfy given quality requirements" (FAO, 2017).

In LEED certification, fundamental commissioning of building's energy systems is a mandatory prerequisite, however, there is a chance to achieve extra credits if the building goes through an enhanced commissioning process. LEED enhanced commissioning requires more activities than fundamental Cx. The prerequisite's intent is "To verify that the project's energy-related systems are installed, calibrated and perform according to the owner's project requirements, basis of design report, and construction documents (USGBC, 2009); while enhanced commissioning awards the project 2 LEED points, the intent of the credit is "To begin the commissioning process early in the design process and execute additional activities after systems performance verification is completed' (USGBC, 2009). Extra activities within the enhanced commissioning process include performing extra design reviews across the various disciplines. Also, additional three O&M related activities are required; developing systems manually, verifying training requirements, and reviewing building operation within 10 months of occupancy (USGBC, 2009). The major activities within enhanced Cx are mainly O&M related activities; which emphasizes the impact of enhanced Cx on the quality of building performance and ongoing building operation. Commissioning in LEED buildings is different from the conventional technical commissioning/ Testing Adjusting and Balancing. Cx is concerned with overseeing and reviewing documents/activities made within all disciplines. According to McFarlane, The Commissioning Authority (CxA) "provides the outline of the commissioning process, which is then implemented by engineers and/or contractors". Technical Cx/TAB is handled within the Cx activities at the construction phase; it verifies the performance of systems, assemblies, and components through measurements and inspections (McFarlane, 2014).

3. A LEED Building in Egypt

3.1 Project Description

3.1.1 Overview

The current case study is one of the new construction projects that fill the heart of New Cairo City in Egypt, a mid-size office building with a total of 72,254 square feet; the area includes seven floors of office space above the ground level and two floors of an underground parking garage. The building is designed to accommodate 160 employees. The project is designed and constructed following LEED certification guidelines version 3 – 2009 and achieved a LEED Gold certificate in 2018. The building is mechanically air-conditioned using two air-cooled chillers above the roof in addition to an individual air-handling unit per each floor, with Variable-Air-Volume (VAV) air supply system distributed over the architectural spaces. Fig. 1.

Figure 1. Photo of the LEED-certified building, New Cairo City, Egypt 2018

Additional pressurization fans are installed on the roof while connected to building floors through ducts to manage the smoke in case of fire. Other systems include lighting, elevators, CCTV, earth-ling network, access control, TV system lighting network, and firefighting. All the systems, assemblies, and components are interfaced with the Building Management System BMS. Electric supply to the building is via 1000 KVA dry type transformer linked to 500 KVA standby generator for emergency loads such as lifts, water pumps, fire pumps, emergency lighting, some outlet receptacles and some air conditioning equipment.

3.1.2 Sustainability Features

Extensive energy and water efficiency measures were applied, also construction materials were carefully selected to ensure achieving the targeted Materials and Resources credits set in LEED. In terms of energy efficiency, the building achieves 20.8% less energy use compared to the ASHRAE-compliant baseline case while 4.4% of the proposed energy use is generated from roof-mounted photovoltaic panels (Fig. 2). As for water efficiency, it achieves a 47% reduction in total annual water use (Fig. 3). Regarding building materials, all installed materials were selected and verified to achieve an environmental goal of 32% regional materials and 12% materials with recycled content (Fig. 4).

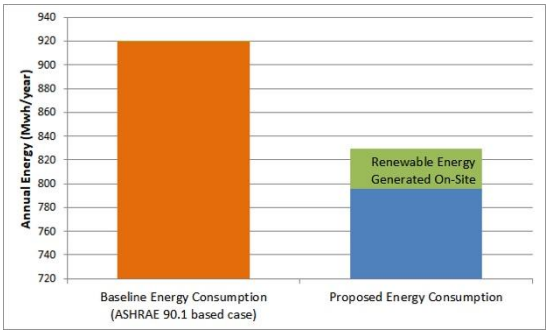

Figure 2. Building's energy efficiency breakdown

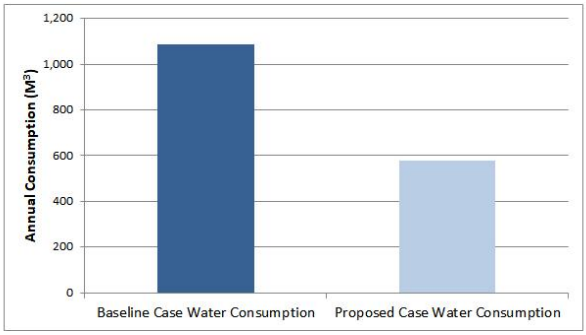

Figure 3. Building's water efficiency

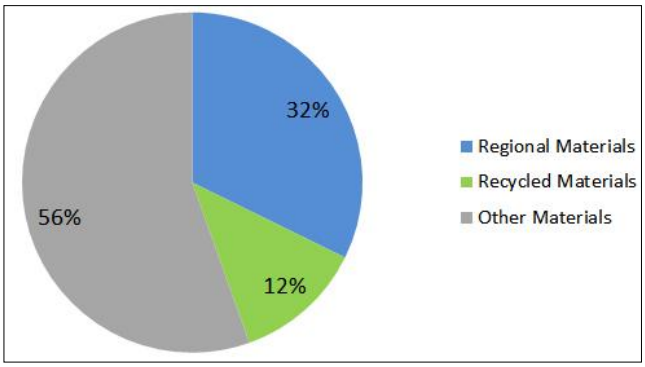

Figure 4. Building's materials breakdown

3.2 The Cx Team

The project's Cx team was formulated by the Commissioning Authority CxA at the pre-design stage and continued to perform the commissioning activities until the startup of building systems. Formulation of Cx team is a cornerstone of the Integrative Design Approach that has been taken in this project, it helped the construction company, and the Operation and Maintenance O&M team to be involved in each design and construction decision from the initial planning until the operation of the building. Each member of the team had significant input in the Cx team's weekly meetings; all requirements, especially operational requirements, were clearly identified in the owner's project requirements and basis of design report, hence, all these requirements and objectives were communicated throughout the project's phases. The Cx meetings followed the Cx team policy, stating that all team members must be informed of all design and construction issues that arise during the process, the intention is to share the decisions of solving any issue based on integrative solutions. The Cx team included: Owner's representative, O&M manager, Project manager, Cx Authority, Cx agent, Project Architect, Project's Consultants, and Construction Manager.

3.3 Cx Activities, Procedure, and Team Policy

In addition to the design reviews, the Cx activities include on-site verification and documentation events concerned with building's energy-related systems such as: All equipment calibration and start-up events, performance verification activities, Testing, Adjusting, and Balancing activities, all airside flushing events, and all waterside flushing events. The Cx procedure and team policy were agreed upon by Cx team members to guarantee commitment and clarity in the correspondence, the policy comprised five enforcements, which are: (1) Once a System is intended for a certain Cx activity, the construction manager must send a notification 3 days prior to the Cx Activity. (2) Any Cx Activity is VOID unless all Cx team members do participate. Documentation requisite before any Cx Activity must be submitted within the pre-mentioned requisite period. (4) All correspondence and submittals must be carbon copied (CC) to all Cx team members. (5) All Cx issues must be Carbon Copied (CC) to all Cx team members.

3.4 Building's Energy-Related Systems

The Cx scope included building's energy-related systems as per LEED reference guide 2009 requirements. In the current building, the scope included Heating Ventilation and Air Conditioning HVAC system, Lighting and Daylight Harvest system, Renewable Energy system, Plumbing, and Building Management System BMS. The details of these systems are briefed as follows:

HVAC: The Building's HVAC water-side comprises two air-cooled chillers, piped via a decoupler to three primary single-speed pumps, and three secondary variable speed pumps. The HVAC's air-side comprises VAV system with electric reheat, and each floor is served by one AHU, except for two floors which has ERV (Note 1) based DOAS (Note 2) for their smoking zones.

Lighting and Daylight Harvest: Building's indoor lighting system is a DALI (Digital Addressable Lighting Interface) system, with a mix of dimming, LED fixtures and on/off LED fixtures spaces. Exterior lighting comprises minimal LED units which are on/off based on photometer's signal.

Renewable Energy: Building's renewable energy is generated via on-grid roof-mounted monocrystalline panels, with peak power of 23 KW, interfaced via one inverter. The inverter communicates with the BMS to provide instantaneous PV generated power, which is shown to building occupants as a percentage of the total consumption.

Plumbing: The energy-related side of the plumbing system comprises two irrigation pumps, three domestic water pumps, and six submersible wastewater pumps. All supply pumps are BMS-interfaced, and irrigation pumps are interlocked with irrigation automated timer to automate irrigation intervals.

BMS: The BMS is a LON (Local Operating Network), linking all energy-related systems, assemblies, and components to one PC located at O&M team's room. The PC communicates with all components via gateways which converts the LON protocol(s) to LAN.

4. Methodology

A mixed-methods research approach was used to achieve the aim of the study; observation, interview of participants, and documents analysis were conducted on the subject case study. A mixed methodology was selected rather than surveys to minimize sources of bias, such as selective memory and exaggeration (Mansour, 2015). The data were analysed to reveal the impact of the main components of building commissioning process on the AEC who participated in the project. The questions used in the interviews were structured to describe the change of behaviour of the design and construction professionals during the design and construction of the project from 2012 to 2017. Also, the authors extracted feedback from participants through informal discussions and correspondences between the project's team for many of the issues raised during the construction. Participants included designers, consultants, project manager, and construction engineers. Furthermore, the study is designed to elucidate the change in behaviour and to confirm the learning experience from the five main components of the commissioning process; Owner's Project Requirements, Basis of Design Report, Design Reviews, Collaborative design approach, and preparation of systems manual. Examples of these questions; What did you learn in this task?, Will you use what you have learned in this task in future projects?, How do you describe your learning experience from the research you have done to do this task?, Do you think you will do this task in future buildings the same way you have done it in this project?.

The interviews aim is to capture the following variables among practitioners:

- new knowledge based on Cx
- change in their quality culture
- Whether there's a developed culture of research
- impact on future projects

Responses were continuously collected from 18 professionals. The collected comments were analyzed and used to support the argument created upon the observations. Table 1 shows the characteristics of the participants.

Table 1. Gender characteristics of a sample

Gender	***Frequency***	***Percentage***
Male	15	83%
Female	3	17%
Total	18	100%
Occupation		
Consultants	5	28%
Designers	3	17%
Construction	5	28%
Engineers	2	11%
Managers Assistant	3	17%
Total	18	100%

According to ASHRAE Cx guidelines (ASHRAE, 2005) and (ASHRAE, 2007), enhanced commissioning process comprises five major practices in order to fulfill the requirements; developing of Owner's Project Requirements (OPR) document, developing Basis of Design Report (BODR), performing third-party design reviews, using integrative design and construction approach, developing a systems manual for the project, in addition to other practices that support these components for enhancing the quality of building design and construction. in the current study, we used these five major components as venues for extracting the information from the participants and project's documents as well.

4.1 Owner's Project Requirements (OPR)

The OPR document acts as a major Cx reference. The OPR is defined by ASHRAE guideline 0 as "a written

document that details the functional requirements of a project and the expectations of how it will be used and operated. These requirements include project goals, measurable performance criteria, cost considerations, benchmarks, success criteria, and supporting information." (ASHRAE, 2005). The requirements within the OPR were communicated among Cx team members, then developed a Basis of Design Report, which is "A document that records the concepts, calculations, decisions, and product selections used to meet the Owner's Project Requirements and to satisfy applicable regulatory requirements, standards, and guidelines." (ASHRAE, 2005).

The whole process was novel to the project team, especially the BODR document that is based on the OPR, it is different from BODR they used to have from designers and project consultants of other conventional projects; design professionals in Egypt are not used to develop such a comprehensive document at the early design phase of other conventional projects.

Here are some of the participants recorded comments; Consultant, "referring to such a live document while it changed over time is a great concept, we have learned to be flexible in our decision and put the owner requirements as the most important factor in our decision". Architect, "we used to have such requirements in our mind, however, this is the first time to have them written in such way like a bible for our project, it is great, we will use the same approach in our future green or not green projects". Mechanical Engineer, "I have done such work before, however, in this project the amount of documentation and follow up by the Owner Representative is quite stressful and useful as well"

4.2 Basis of Design Report (BODR)

Basis of Design Report (BODR) is "a document that records the major thought processes and assumptions behind design decisions made to meet the owner's project requirements (OPR)." The design team uses the BOD document to show how their assumptions and specifications will enable the project to satisfy the requirements listed in the OPR document (ASHRAE, 2005) and (ASHRAE, 2007).

Briones and McFarlane (2013) stated that:

"The BOD transforms the raw data from the owner's project requirements (OPR) document (the "what") into a detailed, technical, actionable plan (the "how") that will meet the owner's objectives—which will also help avoid the "scope creep" that can derail the project schedule and lead to budget overruns" (p. 1).

One of the Cx authority's tasks in the early design phase is to review OPR and BODR documents. In the current project, no BODR was included in early project documents at the beginning, then after being developed, it was observed by the CxA that the systems-specific data are not available, the first BODR version didn't address essential data such as specific codes, performance criteria, BMS requirements, ambient conditions, specific manufacturer makes and models, and, expectations regarding systems operation and maintenance. Requiring and reviewing these data in the BODR is essential for the Cx process, however, asking for this specific data from the project consultants at an early stage of the project is not a common practice in conventional buildings in Egypt. Table 2 shows a detailed comparison between the common practice of designing a conventional building and green building in Egypt. The common practice was thought by the team to be more time-efficient, and that any popping issue during construction can be resolved at its stage of construction. They don't recognize that resolving construction this way can potentially compromise the whole building's quality, since the building is interdisciplinary, and resolving any discipline surely affects the other.

4.3 Design Reviews

Multidisciplinary design reviews were conducted by the CxA repetitively during the design. For us as the project's CxA; the number of issues arose as a result of the design reviews was normal, but the number of review rounds to resolve these issues was doubled in this project. An example of these issues was the selection of the chillers, their efficiency and capacity. Based on the building's detailed energy model, the optimum chillers needed was 2 air-cooled screw chillers, each of 110 TR (Ton Refrigerant). While, at very early stage of design, the MEP consultant designed one water-cooled 400 TR chiller as a common practice for similar buildings in Egypt, successive design charrette and meetings took place to reflect the results of the whole building energy model on the designer's selection, at the end, the whole team agreed upon using the air-cooled system.

Another example is related to the building's Indoor Environmental Quality (IEQ); both thermal comfort and daylight studies were not supplied by the project consultants. After successive reviews, both studies were supplied but noncompliant in terms of form and content. For the thermal comfort study; complying with ASHRAE standard 55 is a must, also, the daylight study should comply with LEED requirements, which was a new practice to the design team at this time.

Here are a few comments of the participants in this research;

A project consultant "we used to coordinate the drawings across different disciplines; however, we used to have some mistakes that need to be fixed during construction. A third-party design review saved us time and helped us with a fresh eye on the project, as you see, although we are having additional number of revisions we are pretty sure that everything is ok". A construction engineer "we are new to this kind of integrated process, we used to get the designs from the main consultant or the designers and any development or modifications always come from them, with no participation from our side, even if we found an issue that needs to be fixed, the solution comes from the consultant with occasional discussions with the construction team. In this project, we feel that our role is more effective, it adds to the quality of the project because of sharing of our experience in finding a solution"

4.4 Collaborative Solutions for Design and Construction Issues

The integrated design and construction approach is used by building professionals in sustainable projects to ensure collaboration between all project parties throughout design and construction. This approach is acquired because the conventional approach that was commonly used in building design and construction "fails to recognize buildings are part of larger, complex systems. As a result, solving one problem may create other problems elsewhere in the system". The integrated design and construction approach Emphasize connections and improving communication among professionals and stakeholder to be able to find the best available and suitable solutions for the design problems to respond to the Owner's Project Requirements. This approach is essential for the design and construction of high-performance buildings as it perfectly matches with the interdisciplinary nature of sustainability.

Managed by project's sustainability consultant and CxA; this approach was implemented by establishing continuous communication among the Cx team, keeping regular active design charrette, applying Cx procedure, and enforcing Cx team policy. This integrative approach was new to all professionals working on this project, however, it went beyond its usual CxA's scope of identifying issues. It helped the whole team to solve disciplinary and interdisciplinary design and construction issues. Some issues were raised by the CxA, such as chillers sizing, chillers efficiency, and adding motorized damper on outside airflow duct to ensure that outdoor air is neither exaggerated nor insufficient depending on zone sensors. Other issues were raised by the owner's technical representative including relocating the CHW differential pressure sensor to account for more reliable readings, and consequently more energy savings. One of the issues raised by the LEED consultant is that the glass partitions won't fulfill negative pressure for smoking zones, and the consultants' team couldn't supply pressurization calculations, therefore the Cx team agreed to place permanent differential pressure sensors on all smoking zones.

Here are a few recorded comments;

As the Project Architect said, "it is fantastic experience, we used to look for this level of quality in our work, however, we were not able to frame such process, or found a standardized system to accommodate in previous projects". A construction engineer "we are new to this kind of integrated process, we used to get the designs from the main consultant or the designers and any development or modifications comes from them, with no participation from our side, even if we found an issue that needs to be fixed, the solution comes from the consultant with occasional discussions with the construction team. In this project, we feel that our role is more effective, it adds to the quality of the project because of sharing of our experience in finding a solution"

4.5 Systems Manual

The systems manual is "A system-focused composite document that includes the design and construction documentation, facility guide and operation manual, maintenance information, training information, Commissioning Process records, and additional information of use to the Owner during occupancy and operations." (ASHRAE, 2013). The systems manual is very specific to the systems within the project and must be easily accessible on-shelf for the O&M team, so it is different from the "manuals" documents which are in stock at the systems supplier. As part of the systems manual; For any system there are 7 items which are normally provided by the contractor in one document to be reviewed by the CxA and handed to the O&M team, those items are: Operating Procedures, Schedule of Maintenance, Manufacturer required Maintenance Procedure, Parts and Recommended Spare parts list, Troubleshooting Guide, System Schematics / one-line diagram, and Supplier's Contact Information. Developing such a manual for this building was a novel practice to the design and construction professionals. Although this process is a pure documentation process which requires neither additional knowledge nor expertise, and although it is crucial for achieving LEED enhanced commissioning points, and for streamlining the building's O&M as well, it took some time to teach the construction professionals how such a document can be developed and help the O&M team.

Recorded comments;

Construction project manager "Having this format for a systems manual is totally new for us, we used to have separate instruction manuals that we are getting from suppliers for each equipment. I'm not sure this format is important to have or not, but I'm sure about the quality we gained from adhering to the LEED certification process". Construction engineer "of course, in this project, we have doubled check everything during the construction, delivery of information, design charrette, and commission process are keys for the high quality we achieved in the construction of this project. Above all of that is the systems manual that guarantees proper operation and maintenance.

5. Results

Green building rating enhances the quality of construction and changes the way professionals handling the architecture and engineering practice in Egypt. The commissioning process major components were influential as they provided the professionals with a learning opportunity that could affect their attitude and working habits in the future project.

The common practice of design and construction in Egypt is disciplinary and quite straightforward in handling a project; it starts with getting a brief about the architectural programme from the owner, this brief includes the number of spaces, sizes and number of people who will occupy the building. The architect plays a major role in the whole design and construction process, he took the brief from the owner, write the architectural program, and develop the architectural preliminary design. Once getting approval from the owner on the architectural preliminary design, the architect develops the drawings, hire sub-consultants to do the structural, electrical, mechanical, and specialty consultants to work under his or her supervision. Solving design issues is laid between the architect and other consultants, neither the owner nor the construction company is involved in solving any design issues. Every consultant works individually on his or her discipline, isolated from other disciplines, the final decisions on building systems must be coordinated and approved by the architect. After having the construction documents done, a construction company should be hired to do the construction either through a bidding process or a selected company that is recommended by the architect to the owner. Throughout this process, the coordination between professionals is to avoid any design or construction conflicts between building systems in terms of space usage and equipment locations. The architect decides on the targeted performance of the building based on feedback from the sub-consultants. At the construction stage, solving the issues goes through correspondence between the construction engineers and the related discipline's consultant under supervision from the architect or the main consultant as long as there is no conflict with other disciplines. Table 2 details this approach, and shows how is it different from the approach taken to achieve enhanced Cx for this specific project in Egypt.

Table 2. A comparison between the processes of design and construction of conventional and green rated building in Egypt

Design Stages	Conventional Buildings (common practice of similar projects in Egypt)		Green Rated Buildings (what happened in the current project)	
	Activities	Professionals involved	Activities	Professionals involved
Pre-Design Stage	Obtaining brief architectural design requirements from the owner – developing the architectural programme – doing site analysis and studies -	Architect	Writing the first draft of the Owner's Project Requirements – Developing the architectural programme – doing site analysis and studies - Developing a Basis of Design Report BODR - developing a commissioning plan	Architect – Structural, Electrical, and Mechanical consultants -specialty consultants – Construction Project Manager – Sustainability Consultant -third party Commissioning Authority
Preliminary Design	Developing architectural design concept with plans and 3d model	Architect	Developing the OPR - Developing architectural design concept with plans and 3d model – developing a preliminary design concept for Structural, Electrical, and Mechanical systems – building energy modelling	Architect – Structural, Electrical, and Mechanical consultants - specialty consultants – Construction Project Manager – Cost Estimator – Energy Modeller -third party Commissioning Authority
Design Development	Architectural design development – Structural design drawings and calculations	Architect – Structural Consultant	Architectural design development – Structural design drawings and calculations – Building envelope drawings – developing the energy model.	The same team in addition to Building Management System Consultant

Construction Stages	Conventional Buildings (common practice of similar projects in Egypt)		Green Rated Buildings (what happened in the current project)	
	Activities	Professionals involved	Activities	Professionals involved
Construction Documents	Architectural, Structural, Electrical, and Mechanical construction drawings – bill of quantities – specifications – Construction Contract Conditions and Terms of Reference (Tender Documents)	Architect – Structural, Electrical, Mechanical, and BMS consultants -	Architectural, Structural, Electrical, and Mechanical construction drawings – bill of quantities – specifications – Construction Contract Conditions and Terms of Reference (Tender Documents) – Add commissioning and LEED requirements – conduct design review.	The same of previous stage
Construction	Shop drawings – Composite drawings – Update project schedule - Supply and install products.	Architect – Structural, Electrical, and Mechanical consultants – Construction Project Manager	Shop drawings – Composite drawings – Update project schedule - Supply and install products - Review all submittals – Review on-site products - On-site progress meetings - Scoping meeting – Mid-construction Cx review – oversee TAB activity - Comprehensive site review	The same team of previous stage in addition to the construction engineers
Pre-Occupancy	BMS programming - Receive manufacturer's manuals – verify O&M inventory – safety drills.	Architect – Structural, Electrical, and Mechanical consultants – Construction Project Manager	BMS programming - Receive manufacturer's manuals – verify O&M inventory – safety drills - Verify training – Building's air flush-out – Review and update systems manual and commissioning report.	The same team of previous stage in addition to the construction engineers
Post-Occupancy Operation and Maintenance	Developing BMS program - Periodic maintenance.	Maintenance Engineer	Developing BMS program - Periodic maintenance - Review building operation – calibrate energy model - implement post occupancy survey – Submit commissioning report and systems manual to owner.	Maintenance Engineer - Energy Modeller - Third party Commissioning Authority

The key to quality enhancement during the design and construction of a green building was the enhanced commissioning in the current project. As shown in Fig. 5 the five major components of the commissioning process have potential impacts on improving the quality and changing the way professional handle each task in the project.

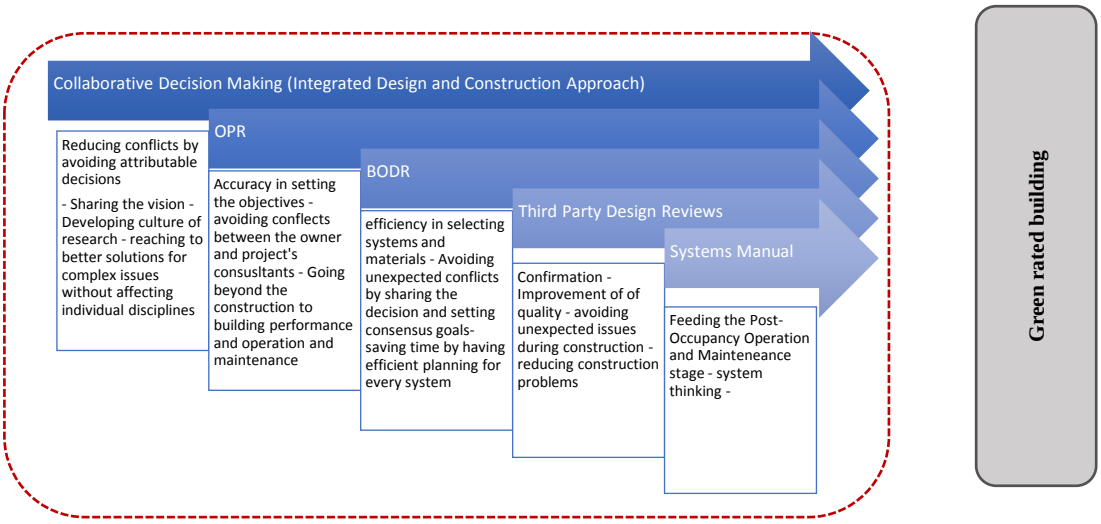

Figure 5. The impact of enhanced Cx major practices on green-rated buildings

In mainstream projects, "Practitioner information-seeking behavior favors oral over written communications, and a reliance on experience and consultation with coworkers and supervisors, until the problem complexity increases and they then consult written sources" (Fraser, Tseng, & Deng, 2018); contrarily, It was noticed that this mainstream behavior among project team did change in the current case, as all team members did favor to refer to documents early before reaching a problem. One main reason for that is raising the potential problems early in the form of a Cx issue during Cx reviews. Another reason is periodic progress meetings, in which team members were more likely to refer to project documents before the meeting. All these precautions ensured documents vitality among Cx team members all along the project's timeline.

While recording each of the design and construction Cx issues, we found that the highest number of Cx issues/notes was raised during the project's design phase. This shows how the gap is significant between a mainstream design process and a commissioned design process. For a mainstream project, these issues wouldn't have been raised as no third-party review occurs at this phase normally; this would have caused cumulative issues as project proceeds. Fig. 6 shows the distribution of the number of Cx issues over the project's phases, it also distinguishes the critical issues from the total number of issues. Critical issues were defined as the design and construction issues that drastically deviate from the main objectives set in the OPR.

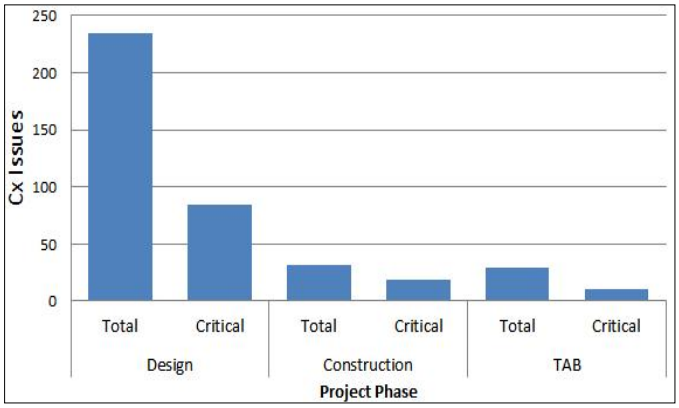

Figure 6. Distribution of the number of Cx issues over project phases

The uncritical issues are mostly issues related to documents formatting and missing details, while critical issues included crucial subjects which had to be resolved before moving to the next project phase. Raising as many issues as possible in early phases had an impact on later phases, such as raising the test plugs issues during construction, facilitated the Testing, Adjusting, and Balancing (TAB) phase.

5. Conclusion

Although the motivation of having a green-rated building in Egypt is the same as in other countries, the current case study shows other significant benefits for the construction industry in a developing country. The observations and recorded feedback of building professionals during the course of design and construction of a newly built LEED Gold building in Cairo show a noticeable learning experience that motivates a change of behavior for building professionals who participated in this project. Such a learning experience will potentially affect the attitude and the quality of future projects for those professionals. A hundred percent of the participants in this study considered the enhanced commissioning process as a learning experience of a new quality approach that will positively impact their future projects. With the increase of demand of green certification from international green building rating systems such as LEED, this case study presents a novel perspective for the green building rating and enhanced commissioning process as a quality management approach that could have an impact on the building industry in the developing countries. Future research is needed to investigate the design and construction quality, and work-related change of behavior of building professionals after working in a series of green-rated buildings in the developing countries. Enhanced commissioning process should also require a record of such a learning experience in the commissioning report because the impact of the process on building professionals as human capital is part of the social and economic dimensions of sustainability.

References

ASHRAE. (2005). *ASHRAE GUIDELIINE 0—The Commissioning Process*. ASHRAE Standards.

ASHRAE. (2007). *ASHRAE GUIDELINE 1.1—HVAC&R Technical Requirements for The Commissioning Process*. ASHRAE Standards.

ASHRAE. (2013). *ASHRAE GUIDELINE 1.4P - The Systems Manual for Facilities*. ASHRAE Standards Committee.

Bampou, P. (2016). Green buildings for Egypt: A call for an integrated policy. *International Journal of Sustainable Energy*, 1-16. https://doi.org/10.1080/14786451.2016.1159207

Cattane, V. (2011). *Green architecture in Egypt: A sustainable project.* Retrieved from Egypt Independent website: http://www.egyptindependent.com/news/green-architecture-egypt-sustainable-project

Cityscape, E. (2016, June 13). *Egypt's Real Estate Sector Remains Buoyant.* Retrieved from https://www.cityscapeegypt.com/en/news/egypt-s-real-estate-sector-remains-buoyant.html

Egypt-GBC. (2010). *Egypt-GBC Ratings.* Retrieved from http://www.egypt-gbc.gov.eg/ratings/index.html

EPA. (2016). *Green Building, Basic Information*. Retrieved from https://archive.epa.gov/greenbuilding/web/html/about.html

FAO. (2017). *Guidelines for quality management in soil and plant laboratories.* Retrieved from http://www.fao.org/docrep/W7295E/w7295e03.htm

Fee, P. (2016, March 21). *Building Commissioning Philosophy.* Retrieved May 8, 2017, from Gsa.gov website: https://www.gsa.gov/portal/category/21596

Fraser, K., Tseng, T.-L. B., & Deng, X. (2018). The ongoing education of engineering practitioners: How do they perceive the usefulness of academic research? *European Journal of Engineering Education*, *43*(6), 860-878. https://doi.org/10.1080/03043797.2018.1450847

Komurlu, R., Arditi, D., & Gurgun, A. P. (2014). Applicability of LEED's energy and atmosphere category in three developing countries. *Energy and Buildings*, *84*, 690-697. https://doi.org/10.1016/j.enbuild.2014.07.095

Mansour, O. (2015). *Enhancing Green Building Performance: A Human Experiential Approach* (PhD, University of Calgary). Retrieved from https://prism.ucalgary.ca/bitstream/handle/11023/2160/ucalgary_2015_mansour_osama.pdf;jsessionid=8A2D87DF8383F9618335570348BC791D?sequence=4

Mansour, O., & Radford, S. K. (2016). Rethinking the environmental and experiential categories of sustainable building design, a conjoint analysis. *Building and Environment*, *98*, 47-54. https://doi.org/10.1016/j.buildenv.2015.12.014

McFarlane, D. (2014). Technical vs. Process commissioning. *ASHRAE Journal*, *55*(6), 14-22.

Mills, E. (2011). Building commissioning: A golden opportunity for reducing energy costs and greenhouse gas emissions in the United States. *Energy Efficiency*, *4*(2), 145-173. https://doi.org/10.1007/s12053-011-9116-8

Mollaoglu, S., Chergia, C., Ergen, E., & Syal, M. G. M. (2016). Diffusion of green building guidelines as innovation in developing countries. *Construction Innovation*, *16*(1), 11-29. https://doi.org/10.1108/CI-09-2014-0045

Perišić, M. M., Štorga, M., & Gero, J. (2019). Exploring the Effect of Experience on Team Behavior: A Computational Approach. *Design Computing and Cognition '18*. https://doi.org/10.1007/978-3-030-05363-5_32

USGBC. (2009). *LEED reference guide for green building design and construction*. U.S. Green Building Council.

USGBC. (2018). Projects | U.S. Green Building Council. Retrieved May 5, 2017, from Usgbc.org website: http://www.usgbc.org/projects

Worldometers. (2017). Egypt Population 2017. Retrieved from http://www.worldometers.info/world-population/egypt-population/

Yu, R., Gero, J., & Gu, N. (2015). Architects' Cognitive Behaviour in Parametric Design. *International Journal of Architectural Computing*, *13*(1). https://doi.org/doi.org/10.1260/1478-0771.13.1.83

Notes

Note 1. ERV: Energy Recovery Ventilation, which is implemented using enthalpy heat wheel.

Note 2. DOAS: Dedicated Outdoor Air System, which is implemented using roof mounted FAHUs.