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ScienceDirect

Procedia Engineering 145 (2016) 211 – 218

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Sustainable Design, Engineering and Construction

Investigating Building Construction Process and Developing a Performance Index

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Abstract

A typical building construction process runs through three main consecutive phases: design, construction and operation. Currently, architects and engineers both engage in the creation of environmental designs that adequately reflect high performance through sustainability and energy efficiency in new buildings. Occupants of buildings have also recently demonstrated a dramatic increase in awareness regarding building operation, energy usage, and indoor air quality. The process of building construction is chronologically located between both the design and the operation phases. However, this phase has not yet been addressed in either understanding contractor behavior or developing innovative sustainable techniques. These two vital aspects have the potential to levy a dramatic impact on enhancing building performance and operational costs.

Repeatedly causing apprehension to the construction industry is a question that posits, "Why is there a gap/delta/inconsistency between the designed EUI, Energy Use Intensity, and the operational EUI"? Building occupants shall not be the only party that bears blame for the delta in energy. It is true, nonetheless, that occupants are part of the reason, but the contractor – as well as the entire construction phase - also remain prime suspects worth investigating. In the present time, research is predominantly focused on occupants (post-occupancy) and designers to educate and control the gap between designed and operational EUI. This research has succeeded in the identification of the construction phase, in conjunction with contractor behaviour, as another main factor for initiating this energy gap. Therefore, not only is the coupling of sustainable strategies to the construction drivers crucial to attaining a sustainable project, but also it is integral to analyzing contractor behavior within each of the construction phases that play a vital role in successfully serving sustainability. Various techniques and approaches will assist contractors in amending their method statements to ensure a sustainable project.

This research correlates an existing project to the two proposed sustainable concepts: 1) Identify cost-saving strategies that may have been implemented or avoided during the construction process, and 2) Evaluate the impacts of implementing these strategies on overall performance. The adopted contexts are to partially foster sustainable architecture concepts to the Contractor

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Peer-review under responsibility of the organizing committee of ICSDEC 2016
doi:10.1016/j.proeng.2016.04.063

process, and then proceed to analyze its cost implication on overall project performance. Results of the validation of this approach verify that when contractors embrace a sustainable construction process the overall project will yield various financial savings. A mixed-use project was utilized to validate these concepts, which indicated three outcomes: firstly, a 25% decrease in manpower for tiling while maintaining the same productivity, thus reflecting a saving of $3,500; next, increasing the productivity of concrete activity, which would shorten the duration of the construction by 45 days and reflect a saving of $1.5 million, and last of all, reducing the overhead costs of labor camps by efficiently orienting temporary shelters, which reveals a reduction in cooling and heating that returned a saving of approximately $10,000. This research develops a comprehensive evidence-based study that addresses the above-mentioned gap in the construction phase, which targets to yield a multi-dimensional tool that will allow: 1) integrating critical thinking and decision-making approaches regarding contractor behavior, and 2) adopting innovative sustainable construction methods that reflect reduction in operating costs.

Peer-review under responsibility of the organizing committee of ICSDEC 2016

Keywords: Sustainable Construction Process; Embracing Sustainable Architectural theories into Construction process; Innovative Construction Approaches; Contractor Behavior; Performance Based Approach; Energy Gap

1. Introduction and Impact of the Problem:

Fluid design, energy-efficient, eco-friendly, naturally lit and ventilated; these are some of the sustainable terminologies we often hear concerning buildings, and they are all very valid concerns. Nevertheless, did you know that the Building Industry consumes nearly half of all energy produced in the United States? In addition, buildings are liable for over 35% of total energy use, as well as being accountable for more than 70% of electricity consumption [1]? The statistics are simply staggering. It is also important to point out that the building industry is regarded as the largest emitter of greenhouse gases on the planet, the greatest contributor to CO_2 emissions and waste outputs [2].

However, research will draw attention to another critical aspect of the building process. There is very little awareness about the complex intricacies that factor into the various phases of the construction process. In fact, the building industry is regarded as the infrastructure on which the economy is built. This fact is very unfortunate for us who work within the field of construction, as a blind eye is often given to the criticality of the construction's impact on the entire process, despite construction representing the main component of the economy. In the United States, more than 7.5 million jobs are sustained within the construction sector alone, proving just how vital this lifeline is to our economy [3]. This research sheds light on the construction process from a sustainable perspective, hence embracing sustainable approaches within the construction industry.

Energy performance ambitions established during the design phase must be carried through all three phases for energy performance outcomes to be achieved. Currently, many architects and engineers provide enhanced evidence-based designs that reflect improved energy efficiency. On the other hand, tenants have demonstrated a dramatic increase in awareness concerning building operation and energy usage. The process of building construction is chronologically located between both the design and the operational phases; however, a lack to understanding of contractor behavior, in addition to the extent of sustainable practices used on-site and how these aspects are subject to affecting a building's energy performance, may be creating a barrier to achieving targeted energy performance outcomes.

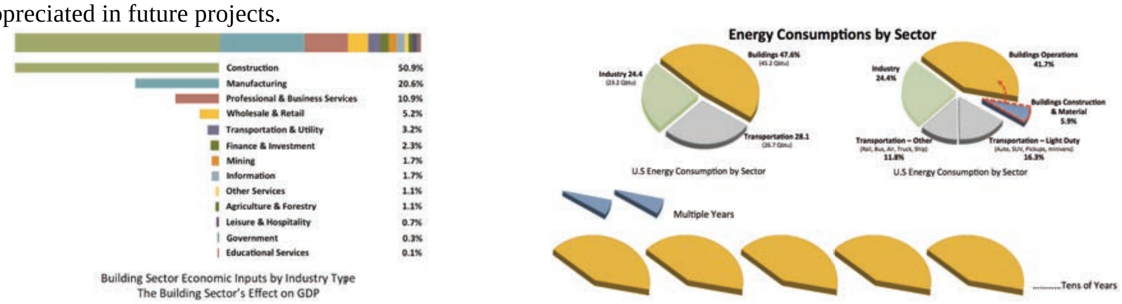
(a) (b)

Fig. 1. (a) Claiming that post-occupancy is the only founder of the energy gap between the anticipated and actual design; and (b) the research's perception of the post-occupancy not being the only factor creating the energy gap between anticipated and actual design.

The contractor is the entity that remains oblivious that the construction industry is evolving to accommodate sustainability. Although the project team exerts extensive efforts to ensure that designs are environmentally sound, techniques that are being implemented during construction to transform the drawings into a structure are neither compatible nor appropriate to serve a sustainable project. Contractor behavior shall be thoroughly examined during the various construction stages. This research serves as an eye-opener to confirm the hypothesis that sustainability should reveal cost-saving to contractors, rather than serving as a supplementary cost. Examining real projects and comparing the costs of sustainable approaches in relation to non-sustainable entities will demonstrate potential savings. The construction process includes many elements and several players who could have an impact on contractor cost-saving. Some of these drivers are the manpower, equipment, materials, construction phasing and mobilization.

2. Impacts of the Problem

The construction industry plays a commanding role in feeding economic growth in almost every country. It is paving the way for a convincing argument for contractors that explains how sustainability will be reflected in money saving. Real life examples from around the world will put an end to the inexperience contractors and will be appreciated in future projects.



(a) (b)

Fig. 2. (a) The construction's fierce impact on the economy [4]; (b) The significant influence of the building construction & Material (5.9%) on the building's operation [5] – Analysis conducted by Authors.

Figure Two reverts to the Architecture 2030 Plan to confirm that the Building Sector touches many other industries and sectors, ultimately affecting the entire economy. Construction represents more than 50% of the industry types that impact the economy. Construction represents more than 50% of the GDP; the graph illustrates the exponentially consumption of electricity within the building operation sector. It is recognizable that the economy of most countries has been affected by construction. The building sector touches many other industries and sectors, ultimately affecting the entire economy. When the Building Sector collapses, the economy is adversely affected. By industry type, construction represents the highest impact on economy. Based on the United States' 2030 Architecture Plan, building construction and materials represent approximately 6% of energy consumption [4]. Although the building operations represent 42%, construction and materials are the phase that proceed and thus govern the effect of building operation. Therefore, underestimating the construction phase will definitely deteriorate the building operation's impact. It is also worth noting that the construction phase lasts approximately couple of years, while building operation's phase stands tens of years, thereof, meticulously steering the construction phase will guarantee better results throughout the entire building process.

On another note, broader problem impacts are obvious. The U.S. predicts a booming building construction process, which is expected to provide healthy and strong economic rewards throughout the next several years. Buildings are a major source of global demand for both energy and material, which are often leading causes for greenhouse gas emissions. According to the U.S. Energy Information Admiration (EIA), the building sector consumes nearly half of all energy produced in the United States [2]. Capitalizing on the aforementioned facts, this research proposal shall serve U.S. sustainability plans. It is predicted that this research proposal will not merely explore contractor behavior, but will also dually introduce and encourage adopting sustainability throughout the construction phase. The amount of energy required by the building operation phase is a multiple of the sum required for building construction and material, yet the impact result of building construction and material dictates the performance's effectiveness and efficiency during the operational phase.

3. Objective

Only with significant developments to the design, construction and operation of buildings, can ambitious sustainable environmental goals be achieved. Therefore, the purpose of this research is to highlight the importance of sustainability in the construction field and encourage contractors and developers to enforce environmental strategies within projects; thus convincing contractors to incorporate environmental strategies while building projects. Despite the fact that sustainable Environmental Strategies are considered during early design stages and during the operation of buildings, construction is often executed without envisioning potentially innovative strategies that could reduce overhead and shorten the project's duration. Therefore, this proposal shall define impeding sustainable strategies that promise potential savings to contractors, and shall deliberately refer to a project to explain its conceivable saving values. Although each project requires unique strategies tailored to match the project, the concepts of the propositioned strategies remain the same. The myth that embracing sustainability will increase cost and delay projects does not play out in reality, as the truth is that sustainability processes should not offset the budget/duration of projects if applied during the initial stages of development, planning and design.

Developers tend to overlook the fact that the value of projects increases when a project is environmentally friendly. As per the Costar-Green study, sustainable buildings are more appealing to clients than traditional ones [6]. Consequently, sustainability should not only focus on buildings, whether during design or as a retrofit, but they should also take heed to the construction and contractors, since the duration of construction is significant.

This section will briefly discuss the intellectual merit of this research. The vulnerability of our resources and human adverse impact on the environment has urged scientists, architects and engineers to rigorously consider sustainability and the built environment. A growing number of academics and multi-disciplinary professionals are conducting research related to sustainability issues, generally focusing on post-occupancy due to the inception that the user's impact on energy is the highest compared to all other factors; while minimal efforts have been directed towards contractor behavior and sustainability strategies. Contractors have been implementing recurring/systematic method statement approaches, which do not reflect sustainability or consider the environment. One of the reasons that this problem exists is that contractors lack awareness of the fact that implementing sustainability is critical to projects and the environment, while the other part of the problem is that new recruits to the construction industry have never been guided or educated to implement sustainability. This research provides a cost analysis to a cross-section of construction activities that demonstrate and convince contractors to adopt such aforementioned strategies.

4. Coupling Construction Drivers & Construction Phases with Building Performance Impact areas

The construction industry has several drivers and activities that comprise the spine of the construction process. Some of these backbone drivers are: (1) ***Human factor***, as productivity rates depend on workmanship; therefore, it is critical that we analyze some of the activities that the human factor adversely impacts the construction process. (2) ***Capital*** of the contractor is another pillar since the equipment, machinery and materials basically control the resources of the project's schedule. (3) ***Contractor's performance,*** which reflect the leading pillar of the construction process; the contractor's construction management plan is an example due to the fact that it dictates the construction process, primarily since construction planning will influence all the method statements of the construction process. (4) ***The Project Team*** representing all parties that maintain either contractual agreement or non-contractual ones.

Research irrevocably associates building environment sustainable impact areas with the construction process, as this is a much-needed principle to successfully not only converting architectural drawings into a sustainable building, but also the construction process shall be as well sustainable. Figure three, represents the matrix of the potential correlations and connections between building performance impact areas (architectural science strategies) with both construction drivers and phases. The lines that connect the contractor's activities with passive sustainable strategies demonstrate these connections. It is clear that most construction activities could employ sustainable approaches. The research provides three examples in the construction recommendation and validation section to encourage contractors to further consider sustainability within the construction process. Several of the sustainable architectural strategies that will be allied are: orientation and geometry, skin, envelope, natural daylight and ventilation, shading, material and resources, energy/atmosphere and human comforts.

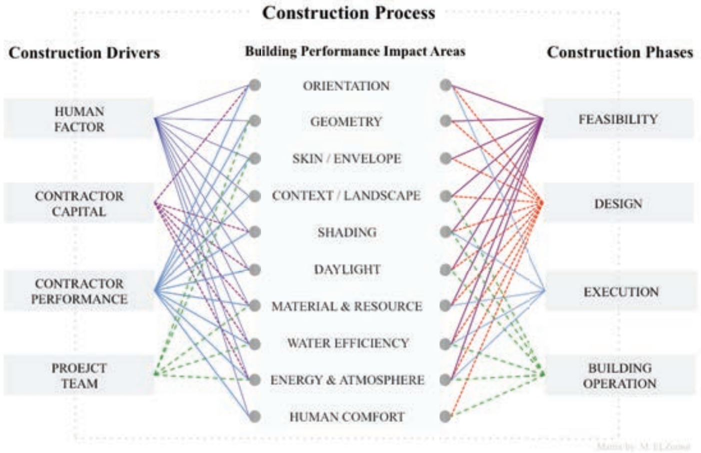


Fig. 3. Bridging the sustainability gap during construction

5. Construction Recommendation:

The research will deliberately provide three examples that successfully exemplify the correspondence between construction activities and sustainable environmental strategies adopted from architectural pedagogies. The first will be the phasing and planning of the construction, where construction method statements should strive for a higher productivity of manpower. Next, will be the labor camp and their suggested orientation, thus becoming energy efficient. Finally, the third example represents a prudent strategy of storing material on-site to reduce handling and installation time.

The project that will be discreetly applied during this research is allocated in Egypt, a mixed-use office-park project consisting of nine seven-storey commercial buildings with retail and F&B worth in excess of $120 million. Construction duration was approximately 4.5 years, which was extended to accommodate further development. The research reverted to this project since all the information and strategies were examined and tested by the Author while holding the position of a D. Project Manager to the aforementioned project.

5.1. Labor Camps:

Labor camps and warehouse areas can be environmentally allocated during the mobilization phase, since locations can be efficiently oriented to reduce the need for cooling and heating. Therefore, providing a pleasant environment to increase the productivity of labors, since they require less amount of rest, allows an increase in the man-hour index. Labor camps serve as a hostel to construction workers, resulting in a reduction in laborers' traveling time and transportation expenses. It is worth noting that most workers live in rural areas, thus the cost of their transport would be very expensive to travel every day to construction sites, not to mention the LCA and environmental impacts of using cars [9]. Therefore, contractors utilize labor camps to ensure control over the project schedule since the labors' focus and productivity shall be merely dedicated to the construction process. However, from the owner's perspective, labor camps are an additional preliminary cost that is paid monthly to rent caravans. Since the owner shall approve payment of an agreed-upon monthly preliminary cost that covers the contractor's expenses; therefore, contractors should attempt to minimize this overhead cost to retain a higher profit.

Although architects/engineers are conscious that the south façade is the best façade - Figure 5 (a) - in terms of performance as its window-orientation is the best option due to the fact that it transmits maximum solar radiation in the winter and the minimum in summer, contractors typically neglect this fact. In this example, the research explores the effect of three alternative proposals; the first two suggestions reflect a minimal south façade percentage, while the third is the optimum solution and most strongly recommended, as it grants the maximum amount of south façade. Therefore, ensuring that labor camps are generally in a shaded area, sustaining a lower cooling and heating requirement for the camps, which is a major overhead cost for projects that require such camps.

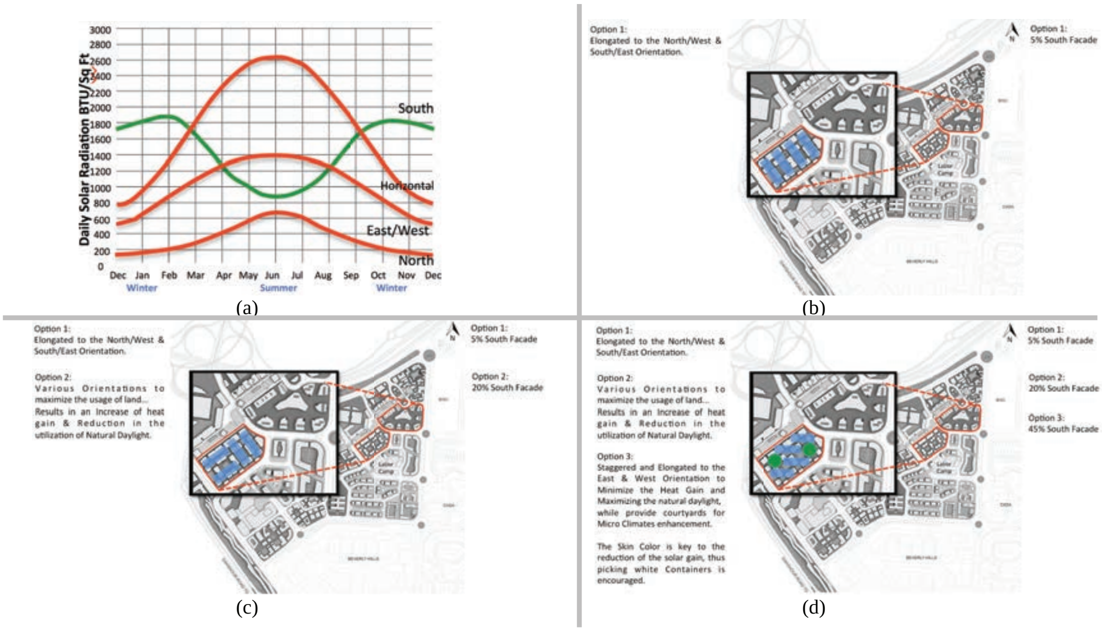


Fig. 4. (a) The South Glazing - Transmits the Maximum Solar Radiation in Winter and the Minimum in Summer (Source: Graph by Authors, inspired by Lenchner,N. [7]); (b) Elongated to the North/West & South/East Orientation thus providing 5% of South Façade; (c) Various Orientations to Maximize the usage of Land, thus providing 20% of South Façade; (d) Staggered and Elongated to the East & West Orientations to Minimize the heat gain and maximize the Natural Daylight while providing courtyards for Micro Climate thus providing 45% of South Façade

The research conducted three studies utilizing e-Quest to qualitatively demonstrate the impact of effective orientation at labor camps. The actual labor camps on the project were comprised of eight caravans, thus the study will consider eight caravans, however, for the sake of illustration, the example demonstrates four caravans only. The first actual setup illustrates an elongated labor camp to the North/West & South/East orientation, which offers a 5% south façade, thus the actual electrical bill cost was $810/month. The second proposal suggests having various orientations to maximize land usage, thus providing 20% of South Façade that reflects a reduced electrical consumption to $740/month. The third proposal displays a staggered and elongated caravan set-up to the East & West orientations, which drastically minimizes heat gain and maximizes natural daylight, while providing courtyards for micro-climate; this effective orientation provided 45% of South façade and thus an electrical consumption of $620/month. From these three scenarios, it is obvious that in a hot and arid region the contactor has to consider the excessive heat during the project's process. If we do compare the first actual arrangement to the third suggested setup, the contractor would ultimately be saving $190/month. By multiplying this sum through the project's duration of four years, it translates to a total saving of $10,200. Although this sum could be considered by some as negligible amount, yet if the contractor embraces other sustainability approaches that address water, heat, waste, artificial lights, generating temporary energy, etc., the savings could be compiled to reflect a higher saving throughout the duration of the project.

5.2. Labor Productivity:

Manpower is one of the key indicators to the success of projects; therefore, contractors depend on competent and professional labors to ensure completing projects on schedule and within budget. This example will explain how a contractor could facilitate an easier job for tiling crews. Tiling represents one of the main trades within the studied project, in terms of cost and time; the planned schedule to finish one building's tiling was approximately three months. This example will only be referring to the handling and transportation affiliated with the tiling's Cost Break-down Structure, and not its installation. Although the traditional scenario of handling and transporting tiles within Egypt is through the employment of manpower to physically carry the tiles to all floors within the building; however the project contractor in our example employed a manual hoist to avoid the exhausting manual transportation of tiles, yet opted to store tiles on the ground floor and to lift the material by hoist to the upper floors, which is still considered an incredibly physically strenuous activity.

The contractor originally planned the following typical scenario: the tiling truck arrives on-site, unloads the tiles on the GF adjacent to the building's perimeter using four labors (to facilitate its handling to the upper floors). Afterwards, when the tiling activity is scheduled to commence, the contractor allocates six labors to move the tiles by manual hoist to the designated floor; these labors only transport materials on-site and are not installers. These half dozen labors are divided as follow: two on the ground floor, two on the dedicated floor beside the manual hoist, and two moving the tiles to their exact location according to the floor plans. Each of these labors pocket a minimum wage of $10/day and require an average of 14 days/building to complete the transportation of material to the various floors.

The research proposal was to increase productivity, and thus decrease the duration of tiling, since tiling is a construction activity on the critical path. Utilizing an existing mobile crane that was allocated on-site, the material would be transported from the truck directly onto the roof; this process saved space on the ground floor for other activities to take place. Exploiting the same manual hoist, transporting the materials to their dedicated floors will be by releasing the tiles instead of pulling them to the upper floors. There are no doubts that releasing materials from an upper floor requires a less amount of human power and energy than pulling materials from the ground floors to upper floors. Initially, the concept provisioned a saving in the total number of labors from four (moving materials from truck to the ground floor) to two helping the crane operator to transport the material to the roof, which took half the time, thus decreasing the labors to just two labors and shortened the duration from one day to four hours. Moreover, the six labors initially handling materials to the dedicated floors were reduced to four, as materials were already on the roof; therefore, by the use of gravity, releasing the manual hoist with less effort reflected a reduction in duration from 14/days/building to 10/days/building.

To summarize, productivity of the tiling activity was increased and thus yielded a decrease in handling duration. Overall savings were labors x 4 days x $10/day x 9 buildings = **$1,400** for transportation and handing of the tiling. In addition, due to shortening the handling portion from 14/days/building to 10/days/building, another saving of 4/day/building x 6 labors x $10/day x 9 buildings = **$2,100** for the moving and handing of the tiles. Therefore, the total savings of both time and manpower is equivalent to **$3,500**.

5.3. Phasing and Planning:

The construction process/method statement should focus on increasing the productivity by effectively embracing a methodology that embraces climate zone, labor comfort, material availability and equipment specs [8]. The phasing and planning example will demonstrate a real-life construction model that mitigates heat; therefore, the productivity of labor increases and shortens activity duration from 21 months to 19.5 months.

Commercial buildings were designed within close proximity to each other; due to the limited area within the project's land, each building's façade was 19 feet from the adjacent building. The contractor's method statement was to build concurrently all the floors, as such, the first floor of the entire mixed-use project would be built simultaneously. The project team proposed a different construction method, which was capitalized on the limited length between buildings. Below are some illustrations correlating with the conventional method and the phased construction approach. The alternating method, phased construction, clusters every three buildings together, thus yielding a saving of approximately $1.5 million. The mix-use project consists of nine buildings, each comprised of seven floors. Assuming that the contractor could only pour three floors each month, the total number of months for concrete work would amount to 21 months. It is also important to take into account that the contractor did not propose using steel formwork or any other advanced method, yet opted instead for a wooden formwork. Each building has its dedicated material, formwork and the contractor hired three manpower crews to be able to complete 3 floors/months. Therefore, the contractor intention is not to share resources.

Consequently, the project team were able to propose clustering buildings together and suggested an alternating construction method. Egypt is located in an extremely hot region, thus the productivity rates drop when manpower suffer from the effects of the heat; moreover, the project team were aware of the heat waves that could threaten the lives of their labors, thus opting to innovate approaches to sustain shading for labors during construction. Once the contractor agreed to implementing such a strategy, an analysis was conducted that evidenced that the duration of concreting activity for all nine buildings dropped to 19.5 months. Since the plan was initially to dedicate 21 months for concreting, the difference of 6 weeks reflected massive savings for both the project and the contractor. The contractor was able to conclude construction earlier, giving him the ability to operate his crews and material in other projects. In addition, the project's duration decreased by six weeks and saved an approximate cost of $1.5 million. This $1.5 million represented a six-week contractor overhead cost equivalent to $500,000. The remaining cost saving, $1 million, was associated with reduction of material and manpower.

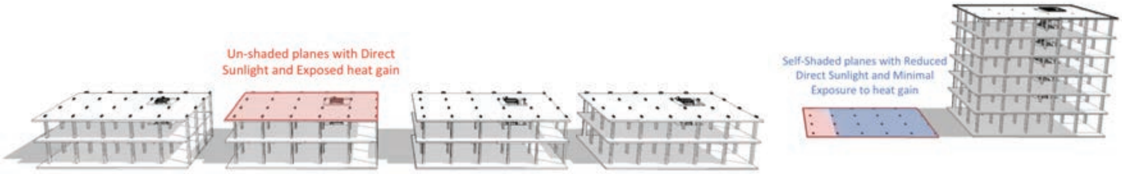


Fig. 5. (a) The default method, Building the Structure Concurrently – Conventional Method; and (b) Alternating Construction Method Statements to provide self shaded planes. Productivity rates are drastically affected by excessive increase or decrease of temperature.

6. Conclusion:

The three primary strata of construction project management are Time, Cost and Quality; these three pillars should always work hand in hand to underwrite success to projects. The research advises that this triangle must include sustainability/performance as the heart of these pillars; with each pillar serving a sustainability objective. Early contractor involvement within projects shall be fostered to certify reducing the gap left by the building process. The research explores misconceptions surrounding the process of building operation in terms of environmental impact, while bridging the gap between the construction process and sustainability. Advocating for further analysis of contractor behavior and embracing energy conservation techniques within the construction process was the primary aim of this research. The construction phase is one of the main areas that require comprehensive awareness and concrete financial justifications, in order to be able to successfully convince contractors to implement sustainable strategies during construction. There is no doubt that various environmental strategies could be utilized to significantly cut construction costs by addressing orientation, energy, water usage, heat, natural ventilation, shading and daylight. Furthermore, pointing out several significant contractors' behavior traits that impact the construction process, hence proposing recommendations for contractors' implementation during the construction phase to reduce the usage of energy supporting a sustainable construction phase. This research should, ultimately, be a template foundation that is attached to any construction tender document in order to encourage sustainable execution during the construction phase.

Acknowledgments

It is with immense gratitude that I acknowledge with deepest appreciation my guru, Nader Chalfoun, who has the attitude and the substance of a genius: a true Energy Legend. Moreover, I also place on record the support and inspirations received by Mounir El Asmar and Noha Al-Awadi.

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