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Cost Analysis and Economical Suitability of Prefabricated Concrete Structures in Building Construction

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ABSTRACT

Construction industry of Pakistan has a great contribution in uprising the GDP of the country. When compared with the construction industries of some developed countries of the world it still lacks in utilizing the modern methods of construction. Most of the organizations are relying on traditional ways of construction and are not ready to equip themselves with the advanced techniques of construction that may help them do their projects more effectively and efficiently. Prefabrication is the future of modern and sustainable construction which can maximize the capability of constructing the structures without compromising not only the time, cost and quality of project but also the environment. Prefabrication is rapidly increasing in construction, and previous researchers have identified various positive impacts of prefabrication on projects. However, prefabricated construction is less preferred over traditional methods of construction in Pakistan. Therefore, a comparison is required between conventional RCC building and a prefabricated (precast RCC) building to unearth the potential benefits of adopting prefabrication on overall cost of project. To achieve this, a BIM based multi-dimensional model of conventional and prefabricated building is developed using Autodesk Revit. A detailed comparison between both the methods of construction with respect to material, labor, transportation and time made the benefits of prefabricated construction clear over conventional construction. Prefabrication method is 84% faster and costs about 13.46% less than conventional method of construction. This comprehensive contrast will help to better understand and encourage the construction industry to move towards the prefabricated construction.

Keywords: RCC Structures; prefabrication; concrete structures; economical suitability; Building Information Modelling (BIM)

INTRODUCTION

The development of the economy and the sustainability of the environment are two of the key effects of the building sector on a nation. Since all the intricate and precisely shaped aesthetic components are built off site and placed afterwards, the usage of prefabricated components in modern architecture is very obvious. Because the ability to manufacture exact and accurate elements is not provided by conventional procedures, engineers are limited in what can be produced using conventional methods. All of these limitations are removed by the use of modular construction, which also offers options for long-term economic and environmental sustainability (Chang 2018). Each project's budget is crucial since it determines how the project will be carried out. Realistically, when building a project, environmental sustainability comes second. In many cases, environmental compromises are made to offset the cost. The traditional ways of building construction are worsening both the economic and environmental issues. Many nations have taken into consideration the current and cutting-edge way of building construction and they have already started the adaptation since the middle of the 20th century. The world population is growing dramatically and the climate change is happening quickly (Chang 2018).

The majority of organizations are accustomed to using their outdated and conventional methods of construction and are not yet prepared to arm themselves with the new, sophisticated, and contemporary methods of construction that might enable them to complete their projects more quickly and effectively (Gallo 2021). To demonstrate why prefabrication is superior to conventional construction, a comparison between a typical RCC building and a prefabricated building is necessary. Using Autodesk Revit, a multidimensional model of a traditional and prefabricated building is created for efficient comparison. The model compares the costs of labor, materials, and transportation. Prefabrication targets the issues with massive waste

production in conventional construction methods, and it also significantly shortens the construction period, saving time and labor costs (Gallo 2021). A few benefits of prefabricated construction are sustainability, moveable pieces, modular design, and quicker construction. It is a developing step toward reducing environmental difficulties since owners may streamline the construction process and reduce waste in this controlled, safe setting. It is an economical construction technique. The purpose of this study is to promote prefabricated construction in Pakistan's construction industry (Steinhardt 2016) (AutoDESK 2021).

LITERATURE REVIEW

The most common and oldest method of building construction is conventional construction. Traditional construction is another name for conventional construction (AutoDESK, 2021). Due to its popularity and familiarity with traditional construction techniques, it is a simple method to use. The most common type of construction among contractors worldwide is traditional construction. Although this method requires more time and waste, it is executed by locals and contractors with little difficulty because it is simple and familiar to the working population. Construction methods and procedures that have been used to build homes and other structures for many years are referred to as traditional methods and procedures. In the United States, conventional building techniques are sometimes referred to as "brick-and-mortar." Some developers refer to conventional methods as "stick by stick." This term alludes to the fact that traditional construction techniques involve a lot of manual labor, from project conception through completion (Gallo 2021).

Modular construction is also known as prefabricated construction. One of the most environmentally friendly and financially secure methods of building construction available today is prefabricated construction as researched by Y. Chang in 2018, allowing to bridge the gap of opportunity to contractors economically and environmentally (Chang 2018). The limitations of material waste and building longevity are removed by prefabricated construction (Legmpelos 2013). Engineers can easily increase the serviceability of a built structure with prefabrication. Off-site construction is the idea behind prefabrication (Legmpelos 2013). Building components used in prefabrication are made away from the construction site and then transported and installed there. Prefabrication is done to control costs and timelines (Badheka 2019). Building quick homes for people affected by disasters like war or earthquakes is made possible by prefabrication (Poon 2004).

Prefabrication has the advantages of being economical, having flexibility in the design model, and taking less time to construct. In research done in 2019 by Shu Wang compares the cost of prefabricated construction and traditional construction and it was observed that prefabricated construction renders more efficient and cost saving building construction compared to traditional method excluding the building code regulations imposed in China which made the prefabricated construction a bit more expensive (Wang et al. 2019). Prefabrication is a concept emerging with a growing manufacturing industry that is becoming widely popular. Prefabricated parts are typically used in large-scale construction projects to address labor shortage issues and reduce labor costs. The return on investment is large in prefabricated construction as compared to conventional construction (Badheka 2019). The actual life span of the building increases and the serviceability also increases. The maintenance of the project becomes easy because of prefabrication and the future repairs become easy to deal with hence it increases the return on investment as compared to conventional method of construction. (Tharinda Rathnapala, 2009)

METHODOLOGY

In the methodology section, we have discussed about the tools that we have used to design our building model. We have used multiple programs for different types of work, such as AutoCAD for plans, Revit for structures, and Lumion 10 for visualization. In traditional construction, the casting of components is done onsite using conventional methods and for prefabricated construction, the casting of components is done off-site in steel moulds as steel is opted for this method of construction because according to American Iron and Steel Institute, steel is a 100% recyclable material (Institute, 2022). The salvage value of steel mould is also worth mentioning because of the fact that steel is 100% recyclable making it beneficial for the manufacturing plant to reuse the same moulds for different projects by slight alterations hence making the salvage value of steel at 90% and leaving a 10% margin for design alterations which results in a return of 90% value of steel used in moulds for precasting in manufacturing plant.

Hyderabad, Sindh, Pakistan's main Phase-1 Qasimabad is where the planned building that will be examined is situated. The structure is 240 square yards in size and has four apartments on two separate storeys in addition to a bank on the main floor. The structure is situated on a central plot with sufficient exposure to the sun and wind. With regard to the current market material rates and labor costs

in relation to the time of construction, we created a cost sheet for the traditionally built building. Next, we created a 4D model of our prefab building, defined its cost, and contrasted it with the cost of our traditionally built building.

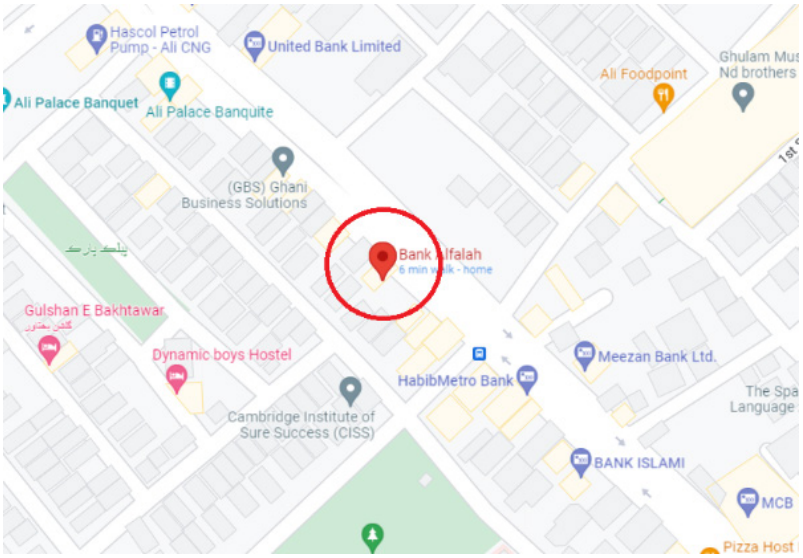

FIGURE 1. Building Location on Google Maps

MATERIAL IDENTIFICATION

The following prefabricated members, which we have modified for use in prefabricated RCC construction, are shown in the figure below as alternatives for slab and walls. Beam and column member design, on the other hand, should be treated as a single entity in both prefabricated and conventional models. The connection of two prefabricated members may result in a small gap between them; this type of gap is typically filled with grout (LEAD, 2022). There won't be many gaps and some connections will be made with grout in the bolted connections we'll be using in this situation. Peikko, a renowned provider of engineering solutions, created the bolted connections that we will use in our prefabricated structure.

FIGURE 2. PPM high strength anchor bolts & installation template

FIGURE 3. HPKM COLUMN SHOE

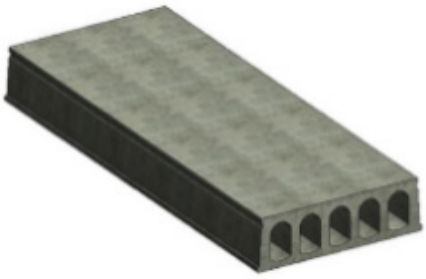

FIGURE 4. Prestressed hollow core slab

FIGURE 5. Light weight hollow core walls

MATERIAL RATES

These rates have been taken from the Government of Sindh's Basic and Composite list of schedules enforced from 7th July 2022. (Government, 2022)

TABLE 1. Rate of materials

Name	Unit	Cost
OPC (Ordinary Portland Cement)	50 KG	Rs. 1000/-
Fine Sand Haro	Cubic Feet	Rs. 37.7/-
Stone crushed graded 3/4"	Cubic Feet	Rs. 53.83/-
M40 Grade Steel Rebar	KG	Rs. 252.52/-
Bricks 9" x 4 1/2" x 3"	-	Rs. 16/-

CALCULATION FORMULAE

Foundation cost is calculated using the volume of concrete and amount of steel used in foundation which is automatically calculated within software. The formula for total cost is:

$$\textit{Total Cost: (Volume of Concrete X Unit Rate) + (Total Weight of Steel X Unit Rate)} \quad (1)$$

The brickwork for conventional building is calculated using the following formula, in which material volume is automatically calculated within the software:

$$\textit{Total Cost: Material Volume in CFT X No. of Bricks in 1 CFT) X 16} \quad (2)$$

M20 (1:1.5:3) Grade concrete volume calculation for conventional building is done automatically within the software, the volume of cement, sand and aggregates is calculated with the help of quantity estimation book by BN DUTTA. The cost is calculated using following formula:

$$\textit{Unit Rate = Cement Bags in 1 CFT X Cost of 1 Bag) +(Sand Vol x Cost Per 1 CFT)} \quad (3)$$

$$\textit{Total Cost: Material Volume in CFT X No. of Bricks in 1 CFT) X 16} \quad (4)$$

The cost of steel is calculated by considering the unit weight of steel, the total bar length is automatically calculated within software and the final formula is:

$$\textit{Total Cost: Total Bar Length X Unit Weight of Steel) X 252.5} \quad (5)$$

The cost calculation for prefabricated beams and column members is done using the following formula:

$$\textit{Total Cost: Unit Rate of Compenent X Total Length} \quad (6)$$

The cost of curtain walls and hollow core slabs are done using the following formula:

$$\textit{Total Cost of Slab = Total Area SFT X Unit Rate of Floor Panel} \quad (7)$$

$$\textit{Total Cost of Wall= Total Area SFT X Unit Rate of Wall Panel} \quad (8)$$

The cost of connections is calculated using the following formula:

$$\textit{Total Cost= Connection Count in 1 Section X Total Sections X Unit Cost} \quad (9)$$

The groutin cost is calculated by determining the wall to wall panel connection and slab to slab panel connection and the formula for those are:

$$\textit{Volume of Grout Required for Panel= Panel Perimeter X (Thickness + 1" Spacing)} \quad (10)$$

$$\textit{Numebar of Beam \& Column Components= Total Length of Component /12} \quad (11)$$

Size of wall panel is (10x10) ft., size of slab panel is (10x15) ft. and size of members are 12ft.

UNIT RATE CALCULATION FOR TRADITIONAL BUILDING

The unit rate calculation (excluding reinforcement) is done by taking the M20 graded concrete under consideration.

TABLE 2. Unit rate calculation for traditional building

M20 Grade Mix Design	Rate
0.35 Bags of Cement	Rs. 350
0.42 Cft of Sand	Rs. 15.834
0.84 Cft of Aggregates	Rs. 45.217
TOTAL UNIT RATE RS. 411.05	
1:6 Mortar	Rate
0.179 Bags of Cement	Rs. 179
1.319 Cft of Sand	Rs. 49.72
TOTAL UNIT RATE RS. 228.72	

UNIT RATE CALCULATION FOR PREFABRICATED

COMPONENTS

The unit rate calculation of materials used in prefabricated components is mentioned in the table below with the exclusion of waste factor since prefabrication benefits in minimizing waste by precisely using the material. The rates of additional components are taken from GOVT'S Schedule of Rates published on 7th July 2022. (Government, 2022)

TABLE 3. Unit rate calculation for prefabricated components

COMPONENT	DESIGN	UNIT RATE
C1 (9"x24")	6 #4 bars | #3 ties @9"c/c	Rs.1391.2/ft
C2 (6"x12")	6 #4 bars | #3 ties @9"c/c	Rs.1160.29/ft
B1 (9"x24")	6 #4 bars | #3 ties @9"c/c	Rs.1391.2/ft
B2 (9"x18")	6 #4 bars | #3 ties @9"c/c	Rs.1179.9/ft
B3 (6"x18")	6 #4 bars | #3 ties @9"c/c	Rs.851.306/ft
Slab	Pre-stressed hollow core slab	Rs.150/ Sq.ft
Wall	Hollow core wall	Rs.80/Sq.ft
Base Connection	Baseplate Anchor	Rs.1267 /piece
Screw	Screw 8"	Rs.253.75. /piece
Grout	Grout (1:4)	Rs.236./CFT
Formwork	Steel Moulds	Rs.15000/piece

LABOR COST

The labor cost for traditional construction is calculated using the method provided in the book of quantity estimation by BN DUTTA (Dutta, 2017). The cost of prefabricated construction labor is calculated by performing a pilot study in which ten construction firms are approached and are requested to give interview of their skilled labor after which the requirement of labor to install single component is averagely estimated which is then multiplied by the volume of work to be done in a single shift. It is necessary to mention that skilled labor is required because of complex bolted connections involved in the prefabricated construction.

DATA COLLECTION AND ANALYSIS

The data for hollow core wall and pre stressed hollow core slab is collected from the manufacturing plant "HUMECRETE CONCRETE MATERIALS" located in the site area of Hyderabad, Sindh region. The data for steel moulds which are to be used in prefabrication, are also provided by "HUMECRETE CONCRETE MATERIALS". The total number of moulds required are 349 in two phase precasting (Poon S, 2004). The data for bolted connections is taken from Piekko Engineering and the data for construction timeline is provided by "HUMECRETE CONCRETE MATERIALS". The data for traditional construction time is taken as an average from a survey conducted from different construction companies in Hyderabad, Sindh region.

COST SHEET FOR TRADITIONAL METHOD OF CONSTRUCTION

The cost sheet for traditional method of construction is generated by calculating the values using equations 1,2,3,4 & 5. The following table contains the data which is calculated:

TABLE 4. Total cost of traditional construction

CATEGORY	COST
Structural Floors	Rs. 1525803/-
Structural Columns	Rs. 600844.32/-
Structural Foundation + Reinforcement	Rs. 406035/-
Structural Beams	Rs. 486024.04/-
Total Reinforcement (Excluding Foundation) (Total Weight Including Foundation = 17.69 Tons)	Rs. 4239933.94/-
Brick Work	Rs. 2198419/-
Mortar Finish	Rs. 2574239/-
Labor Cost	Rs. 1858948/-
Formwork Cost	Rs. 810431/-
TOTAL COST	Rs. 1,47,00,677/-

Total cost of construction is Rs.14.7 Million and total area of construction is 6480 Sq.ft. and for that, the rate of construction is calculated to be Rs.2269/Sq.ft. only.

COST SHEET FOR PREFABRICATED CONSTRUCTION

The cost sheet for prefabricated method of construction is generated by calculating the values using equations 6,7,8,9, 10 & 11. The following table contains the data which is calculated:

TABLE 5. Total cost of prefabricated construction

CATEGORY	COST
Beams & Columns	Rs.3154199/-
Curtain Wall & Hollow Core Slab	Rs.5443220/-
Bolted Connections	Rs.1017268/-
Grouting Cost	Rs.349575/-
Plant's Profit (10% of Material)	Rs.996426/-
Onsite Labor & Machinery	Rs.799569/-
Steel Moulds	Rs.5235000/-
Salvage Value of Moulds	Rs.-4711500
Transportation (Two Shifts)	Rs.40000/-
Foundation Cost (Conventional)	Rs.406035/-
TOTAL COST	Rs.12729792/-

The total cost without salvage is calculated to be around Rs.17.44 Million and by considering the salvage value, the total cost of the prefabricated project is about Rs.12.72 Million. The unit rate of the prefabricated construction considering salvage value is calculated to be Rs.1965/Sq.ft. Only.

CONSTRUCTION DURATION

We conducted ten separate construction company interviews in Hyderabad, Sindh, Pakistan, and using the results of the pilot study, we came to the conclusion that the conventional method of construction takes an average of 192 days to complete as shown in the figure 6.

We have developed a project timeline for the prefabricated construction, and using this timeline, we have determined that the prefabricated construction project will take a total of 30 days to complete as shown in figure 7.

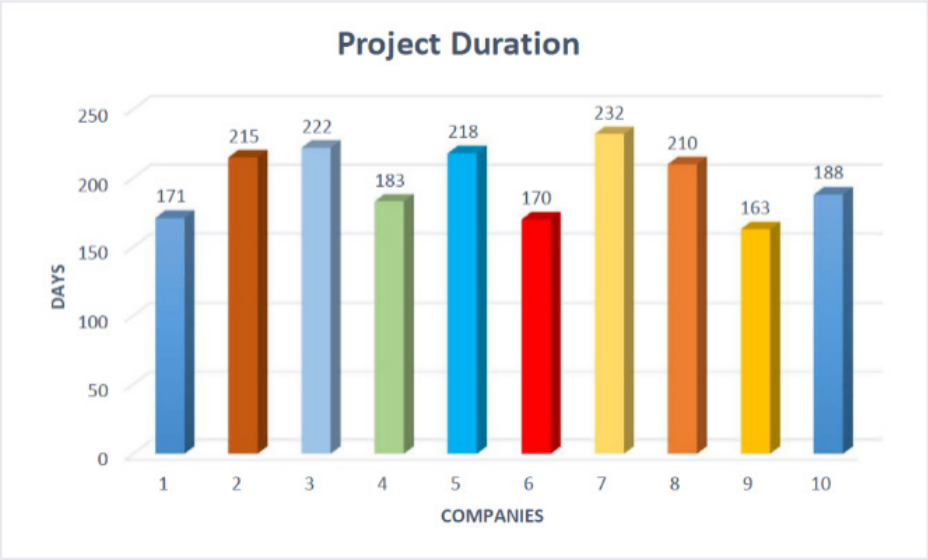

FIGURE 6. Traditional construction duration

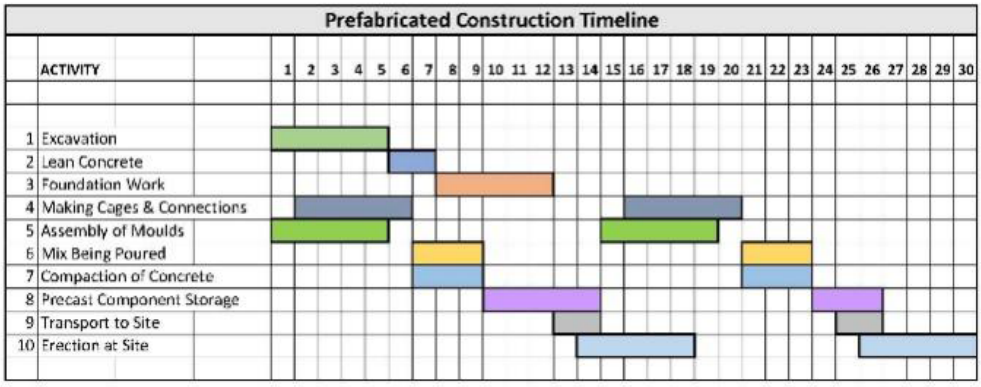

FIGURE 7. Prefabricated construction timeline

CONCLUSION

According to the research and analysis carried out to meet the goals, prefabricated construction is preferable to traditional construction. The prefabricated method of construction is therefore quick and affordable. The prefabricated construction is also environmentally friendly according to the environmental impact assessment performed by Miran Seo (Seo, 2020). Prefabricated buildings cost 13.46% less to construct than conventionally built buildings, and they also take about 84% less time. A margin of error of 1–2% is taken into account when estimating various costs and components because it is noted that cost estimations involving complex engineering design and methodology are always different from the actual cost, which is known after the actual completion of the project. Our pilot study revealed that only a small percentage of construction firms actually favor prefabrication, and the majority of firms view technical design and client resistance as resistance factors (Chittiprolu, 2014).

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

AutoDESK, 2021. Revit: BIM software for designers, builders, and doers. [Online].

Badheka, D., 2019. Does Prefabrication boost ROI in construction or disrupts the project?.

Chang, Y. L. X. M. E. Z. L. H. Z. &. R. R., 2018. Unlocking the green opportunity for prefabricated buildings and construction in China.

Chittiprolu, R. K. R. P. &. P. K. R., 2014. Seismic Safety of Joints in Precast Buildings A State-of-the-art Literature Review.

Dutta, B. 2017. *Estimating and Costing in Civil Engineering 25th Revised Edition.* s.l.:s.n.

Gallo, P. R. R. &. B. E. 2021. Smart green prefabrication: Sustainability performances of industrialized building technologies.

Government, S. 2022. [Online] Available at: https://pnd.sindh.gov.pk/Schedule

Institute, A. I. a. S., 2022. [Online] https://www.steel.org/sustainability/

LEAD, C. 2022. What is Grouting? Types of grouting and its advantages and disadvantage. [Online].

Legmpelos, N., 2013. On-site Construction Versus Prefabrication.

Poon S, T. Y. A. &. J. L., 2004. Reducing building waste construction sites in Hong Kong.

Seo, M., 2020. Environmental impacts of prefabricated construction: CO2 emissions comparison of precast and cast-in-place concrete case study.

Steinhardt, D. A. &. M. K., 2016. Adoption of prefabricated housing-the role of country context. *Sustainable Cities and Society.*

Tharinda Rathnapala, D. G. 2009. Towards a framework for incorporating prefabrication processes into building information modelling.

Wang, S., Zhang, H., Wang, C. & Wu, Y. 2019. Cost analysis between prefabricated buildings and traditional buildings.