Prefabrication, Sustainable Technique in Building Construction

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ABSTRACT
Prefabrication, whether full-volume or component-based, only affects the construction process without affecting the final product. Prefabrication use provides an alternative route for procuring a building that can provide the opportunity to benefit from changes in the construction process. The paper outlines the history and raises the level of interest in prefabrication techniques as well. The benefits of using prefabrication includes higher quality products for clients, improved productivity and profitability for contractors and environmental benefits associated with its use. Barriers to prefabrication are presented from the perception resulting from past mistakes. The prefabrication sustainability characteristics are qualitatively expressed as generally favorable compared to conventional on-site purchases, but, the quantitative performance remains to be defined. The Prefabrication can have an economic, social and environmental impact in the construction industry. It is important that how much of a potential difference it can make. Steel being a flexible, durable, low cost construction material supports for speedy and safety construction compared to precast concrete construction. Lastly, a case study of world’s tallest prefab tower is discussed highlighting its success out of criticisms and doubts it faced during its construction.

Keywords
prefabrication, sustainability, sky city.

1. INTRODUCTION
Popular use of prefabricated structures is being observed in buildings construction due to the introduction of a new guideline encouraging the use of precast facade as a form of green elements in construction. As their name implies, prefabricated buildings are structures built by manufacturers and then installed in the selected location.

The prefabrication of the manufacturer can vary from structure to structure, but usually most of the building is built off-site. In most cases, this drastically reduces construction time and cost, and allows construction to occur, regardless of environmental conditions.

Prefabricated buildings can be designed for virtually any use, but are ideally suited to operations need temporary structures, less construction time, and relatively less expensive construction costs. They are also an excellent solution in locations where conditions prohibit or otherwise spoil site construction. For example, a prefabricated building may be used for an office of mining site or as a guard column for temporary military base. Modular and prefabricated structures also serve as conference facilities, arenas, convention locations and event centres. In terms of agricultural capacity, they can be as a storage, a staging area or housing.

Modular houses, as prefabricated dwellings are otherwise known, are generally shipped to their final location through heavy-duty flatbed trucks. In the case of large buildings, such as two- and three-story units, the operation require multiple vehicles. Construction materials include metal, wood, concrete, and a variety of other materials typically used in building and factory engineering.

Background and history of prefabricated Structures:
It had been used once in early 1970s in a pilot project to construct a series of 17-storey public houses, used in a broader scale in the 1980s in the construction of public houses where all the façades of the flats were constructed in precast manner, improve public housing by introducing in-situ joined façade and wider use of other precast elements in 1990s, packaged projects introduced from late 1990 onward by for the construction of a series of schools using semi-prefabricated method, a series of government quarter buildings using similar construction techniques were introduced in 2000, buildings like bus depot and train station platform used large amount of prefabricated elements in that some were primary structural members (1997 onward), popular use of prefabricated external wall from 2002 onward in residential buildings.

Prefabrication – Concept, Benefits & Limitations:
Components that are assembled in a factory or other manufacturing site, and a structure that transfers complete components or subassemblies to the construction site or to be positioned. It is a combination of good design and modern high-performance components and quality control manufacturing procedures. This work is carried out in two stages, that is, the parts are manufactured outside the final position and installed in place.

Benefits of prefabrications are as follows:
• Saving in cost, material, time & manpower.
• Shuttering and scaffolding is not necessary.
• Installation of building services and finishes can be done immediately.
• Independent of weather condition.
• Components produced at close supervision, so quality is good.
• Clean and dry work at site.
• Possibility of alterations and reuse.
• Correct shape and dimensions and sharp edges are maintained.
• Very thin sections can be entirely precast with precision [8].

Limitations in use of prefabricated structures are:
• Handling and transportation may result in damage to members in transport process and require additional setting.
• It is difficult to connect the prefabricated unit to produce the same effect as the monolithic. This leads to non-monolithic construction.
• They should be placed in the proper position, otherwise the load on them may change and the member may be affected.
• Erection equipment required.
• Transport cost is high.
• Trained labour and quality supervision is required.
• Prefabricated components and prefabricated structures eliminate the space and time of traditional structures. Although prefabrications are used to a large extent in a variety of countries, in India, the construction industry continues to use the same conventional approach, despite its expansion. The root cause of problems is that most families do not have the confidence to build prefabricated houses [8].

2. BARRIERS TO APPLICATION
The following questions have been identified as barriers to ingestion from the Desk study

2.1 General Image
The image of prefabrication is coloured by the experience of past application, from the results of the ancient high rise housing systems.

Many of these problems come from workmanship, not design flaws. These experiences constitute a barrier to some parts of the construction industry and accept prefabrication as a viable alternative to building procurement. However, this situation is now being addressed through close monitoring of field activities, ensuring that the end result is a product with a process quality comparable to that of traditional systems. The quality of the assembly is important to ensure the long-term success of the prefabricated system, and whether the skills necessary for successful implementation are the core of past mistakes.

Now the prefabricated test is turned to mainstream development. For non-residential buildings, due to the needs of major customers, they want to improve the efficiency and speed of their purchase of buildings, so in the process more widely accepted the use of some prefabrication.

2.2 Perceived Performance
Much of the prefabricated housing that was built earlier has been viewed as having a shorter lifespan than that of equivalent traditional buildings.

The prefabrication of non-permanent solutions is one of the potential barriers to its widespread acceptance as a mainstream procurement option. The introduction of the entire life cost calculation as a tool to view the impact of different design strategies will be applied to the building into the prefabricated system, enabling the customer to obtain a building with known financial impact in its useful life.

2.3 Customer Expectation
A particular obstacle to the use of prefabricated systems in houses is the public's perception of traditional brick finished houses. The wooden frame housing system is typically accomplished with a brick outer cladding, and other innovative systems include brick tiles that are mechanically secured to the outer surface of the wall to attempt to mimic the traditional surface. The masonry industry is developing new factory prefabricated systems that can be transported to the site and will allow additional routes for delivery of homes that maintain the traditional masonry appearance when delivered through prefabricated routes. The Housing Association is starting to purchase a multi-unit housing estate with prefabricated systems, with positive feedback from residents. This is a domestic housing problem, non-residential sector customers are more receptive to the building with innovative and non-traditional look.

2.4 Industry Culture
One of the factors limiting the use of certain forms of prefabrication in housing applications is the availability of equipment for handling large prefabricated systems in the field. This is a problem specific to the housing construction sector, as the use of appropriate factories is more extensive in non-domestic markets. Some manufacturers offer their truck delivery systems for cranes to enable the installation of prefabricated parts, however, where the system needs to be adjusted later, a location-based plant is required. The industry is to some extent by modifying the existing equipment (usually an excavator) to solve this problem so that the prefabricated parts can be suspended below the excavator arm to move around the field. Changes in site culture and plant use will make it easier to develop panels for prefabricated systems.

2.5 Product Awareness
Procurement of prefabricated parts of a project is usually a matter of the designer's awareness of the availability of a given system. Designers are less likely to use the system where they do not appreciate the benefits of the building, or they do not understand how the system affects the design process. Manufacturers are producing innovative prefabricated products; they think the designers are conservative and unwilling to try new systems [2].

3. SUSTAINABILITY ASPECTS OF PREFABRICATION
Throughout the world, countries are working to cope with the growing problem of unsustainable development. The result of this struggle, which is evident in the highly developed and still developing countries, is closely linked to the pressures of economic progress. While it is critical to development, infrastructure construction, maintenance and demolition require significant material flow, high energy demand, and irreversible impacts. The framework for sustainable infrastructure design should review the economic impact of new prefabricated and construction technologies, alter the structural industries of cement and concrete products using social impacts such as "green" building materials and...

45
Prefabricated construction has been identified as having a role to play in making construction activity more sustainable. Prefabrications are generally aimed at:

- Developing prefabrication with optimal flexibility and functionality;
- Improving more efficient technologies (reduced materials input and costs);
- Increasing quality of product.

The following sections consider the environmental economic and social aspects of sustainable construction.

### 3.1 Environmental Aspects

Following six indicators are to be measured:

1. Operational Energy Use
2. Embodied Energy
3. Transport Energy
4. Waste
5. Water
6. Species Index per Hectare.

By suggesting that prefabricated performance is being considered in at least three "Innovative" sustainable development performance indicators compared to traditional buildings.

Another important factor associated with prefabrication technology is the reduction of building-related waste. The impact of buildings on local ecology and species will be strongly influenced by design and landscape, depending largely on whether the building is purchased through traditional or prefabricated routes. However, a very important issue is related to the damage caused by pollution during construction. Prefabricated buildings should have more control over plant-based prefabricated, which should reduce the risk of contamination of the local environment.

Transport may be an environmental performance factor, where prefabrication may be worse than traditional buildings. In the case of volume construction, in particular, the transport of parts to the site requires the movement of some volume of air, which is not as effective as the more traditional transport.

Manufacturers of some prefabricated components are actively considering the environmental impact of their products by developing materials procurement, recycling, pollution control and waste minimization standards (eg Trent Concrete).

### 3.2 Economic Aspects

The Prefabricated project aims to deliver:

- A) Reduction in construction costs;
- B) Reduction in construction time;
- C) Reduction on defects on completion.

If these are confirmed, these types of improvements will indicate that prefabrication can play a major role in achieving Egan goals and can be part of the economic aspects of sustainability through prefabrication.

### 3.3 Social Aspects

The prefabrication of the housing sector is the challenge that, in some extreme cases, certain types of institutions are associated with low quality housing and even social exclusion. This is the root cause of the success of the housing sector prefabrication, both designers and manufacturers need to accept this. If the prefabrication is linked to these issues again, there will be risks that are considered socially unacceptable systems, regardless of other technical advantages and environmental benefits, and will be considered a failure. The situation of non-domestic buildings is quite different. Over the years, some retail development, fast food restaurants and hotels have been procured through prefabricated buildings. Few, if any, social problems are associated with these through prefabricated purchases, and in many cases few people are aware that they are so [2].

### 4. PREFABRICATED CONSTRUCTION AND OPERATIONS MODELING

To demonstrate the impact of the proposed prefabricated construction technology on sustainability, the research team will: a) document the sequence of construction operations required to erect a structure using traditional cast-in-place techniques; b) design and verify the robustness of construction work and constructability of a structure using prefabricated construction techniques; and c) quantify the impacts on construction (i.e. time required for construction, fuel consumption, construction waste generation, length of traffic closures, etc.) when constructing a structure designed using prefabricated elements. The design and comparison of alternate construction techniques and their measurement of impact on sustainability will be carried using discrete-event simulation.

Discrete Event Simulation (DES) is a powerful objective function evaluator that is well suited for comparison of alternative construction methods. For each method, a process model describing the build operations required to build the structure is created. These models take into account the different resources required to perform the construction, the rules that perform different operational tasks, the management decisions made, and the random nature of the events. And then the simulation of the operation of digital simulation, and study the operational performance of the statistical measurement. The results will include construction costs and time as well as resource utilization, queue waiting time and length, service interruption time. The results will allow verification of construction techniques used with prefabricated concrete components and will allow for objective comparison and proof of the impact on sustainability. The simulation results also point to an important part of the operation, with potential improvements that could lead to cost or time savings [3].
5. PREFABRICATED STRUCTURES
The job site condition is an important factor in determining the use of prefabrication / modularity, depending on the accessibility of the job site, the number of stories, and the external type of the building.

5.1 Various prefabricated structures
Various prefabricated structures are being developed, such as prefabricated steel construction, precast concrete construction, prefabricated wood construction, prefabricated plastic construction, prefabricated glass construction.

5.2 Value Benefits of Steel Construction:
The steel frame structure offers many advantages over traditional reinforced concrete, and lower cost, sustainability and flexibility are many of the benefits of selecting steel structures.

Steel structures using prefabricated steel frames can reduce overall building costs by 2-3% compared to reinforced concrete. Taking into account the inflation, steel costs in real terms fell by 14%. During the same period, the actual cost of concrete construction increased by 16%.

Prefabricated steel construction uses off-site prefabrication to improve the speed or erection of the solution and cost predictability. The Prefab steel structure offers many advantages, as outlined below.

Table 1  Summarizing the Advantages of Steel construction

<table>
<thead>
<tr>
<th>Value for money</th>
<th>Flexibility</th>
<th>Speed</th>
<th>Safety</th>
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<tbody>
<tr>
<td>Steel is an-economic construction material</td>
<td>In design</td>
<td>Prefabrate d structural steel solutions</td>
<td>During design and fabrication</td>
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<td>Continuous development of steel frame technology</td>
<td>During Constructio n</td>
<td>Short construction period</td>
<td>During constructio n</td>
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<tr>
<td>Built in a short construction period</td>
<td>In use</td>
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6. PREFABRICATED STEEL CONSTRUCTION CASE STUDY
Sky City is a pragmatic building made with the technology and vision of “Sustainable Building”. It is built in China with Pragmatic, Multi-use, Medium-priced, 7-month completion. It is an 838-metre-tall (2,749 ft) planned skyscraper in the city of Changsha, Hunan in south-central China.

Sky City is an “inclusive community” building with a variety of functions, people can live, work, shop, entertain, go to school and see a doctor under the same roof. Sky City aims to reduce the city's dependence on roads and vehicles, thereby reducing traffic congestion. This is the “zoning community” revolution. In the city of the sky, in addition to the crematorium, you can find anything you need from the cradle to the grave. This eye-catching feature can awaken those who turn the livable city into a city that relies on vehicles. So, Sky City is not the destruction of the city [7]

Sky City is an eco-friendly city because when you build high land can be used more efficiently, thus saving more land for trees and fields, which is certainly more environmentally friendly than the lower and spreading cities. Sky City can save up to two square kilometers of afforestation, you can plant 100,000 trees. What beautiful pictures!

The sky city is accused of wasting energy and is therefore anti-environmental. This is a fundamental mistake. In fact, the city of the sky not only has 20 cm insulation, but also four windows. Its insulation effect is even better than the refrigerator. Plus heat recovery of new fans (Figure 1), LED lights and power elevators, reasonable professionals will certainly agree that no other building is more energy efficient than the sky city. Heating and cooling consume 30% to 40% of the world's energy, most of which is due to the poor insulation of the external walls and windows. All building materials are tested for formaldehyde, lead, radiation, etc. and are qualified. Each household is equipped with an air quality monitor that detects PM, VOC, CO2 over 24/7. Sky City for health protection.

Sky City is marked as a project, some officials of the window ornaments, some of the company's image decoration and some rich wealth exaggeration, which is an underground guess. The fact is that even if an official has not issued any incentive policy, the top floor apartment has no room left for the luxury headquarters (office space below 15th floor). Its budget is 9 billion yuan, did not leave the wealth of space. Sky City consists of 1160 sets of 60 square meters of apartments, 1398 sets of 90 square meters of apartments. So the rich may not want to live in such a small apartment. There are 1892 units, more than 90 square meters, accounting for 43% of the total. This mix is by no means upscale. Location is remote, also decided not to sell at high prices. The city of the sky is built to solve the housing problem of the people. As a result, Sky City has lower turnover, higher efficiency, and close to zero material waste.
Sky city construction in 7 months of construction time, which is considered too short, can not be true, it must speculation, the quality can not be guaranteed. But it's the truth! It creates ultrafast expectations and modular technology involved. More than 20,000 workers produce products at the factory for 4 months. More than 3,000 workers have been working in the field for three months. For full-time and diligent workers, these working days are sufficient for buildings with a building area of 960,000 square meters. Competencies and qualifications are the basis and the cost of installing the contractor's dual core partners.

Sky city also give priority to safety construction. They have conducted hundreds of experiments with domestic and foreign experts; for example, for the wind tunnel (Figure 2), we have done four experiments in three laboratories in China and abroad.

Fig.2 Tunnel Test   Fig.3 Seismic Model

In China, there are no laws, regulations and regulations on what kind of steel should be used for high-rise buildings, and for Sky City, they imported hundreds of thousands of tons of steel from Luxembourg, which is the world's leading steel supplier. Luxembourg steel has been very expensive, even without high tariffs and huge logistics costs. This proves that safety is prior to environmental friendliness. Sky City also strive for longer life. In the past, high-rise buildings are in the form, The Sky City is a solid pyramid structure.

Fig.4. Sectional floor plan   Fig.5. Arrays of columns and beams

- Complete symmetrical pyramidal structure.
- All steel light-weight structures enjoy the best ductility.
- Stand against Magnitude 9 earthquake
- All steel columns are wrapped in ceramic fibreboard with a minimum of 3 hour fire-retardation
- Over hundred times of physical strength test & fire resistance test were performed, five wind tunnel tests were conducted by four research institutions both at home and abroad.

Sky city strives for higher life Quality also. It offers residents with an open city-like space for play.

Fig.6. Open spaces in sky city tower

- A walking street 10km long connects from the 1st floor to car driving) 170th floor
- 56 sky parks of 10 m tall space at 480m2 each along the street.
- There are city squares, children’s playground, basketball tennis & badminton courts, swimming pool, theater, cinema, park, flower nursery located in all the sky parks 86,400m2 vertical organic farm, other city entertainment & sport facilities rural scenes.
• 8,000m² of open sky gardens. Additionally, residents can be part of the thick trees as long as they go out, as the skyscraper has emptied much space for green lands.
• Living space enjoys flexible configuration, the span is 15.6m x 15.6m[1]

5.1 Prefabricated building components of Sky City.

Every step for construction speed was well planned, right from how it designs floor modules to how workers load the trucks.
The floors and ceilings(fig.7) of the skyscraper are built in sections, each measuring 15.6 by 3.9 meters, with a depth of 45 centimeters.

![Fig.7 Floor and ceiling panels](image)
Each load carries two modules to the site, with the necessary columns, bolts, tools, and other peripherals to connect them stacked on top of each.

![Fig.8 Module Loaded Truck](image)
Each section is lifted by crane directly to the top of the building. Workers use the materials on the module to quickly connect the pipes and wires.

![Fig.9 Erection of prefab panels](image)
The design has aced 9.0-magnitude earthquake tests. The reason: this unique column design, with diagonal bracing at each end and tabs that bolt into the floors above and below (fig.9).

In the final step, heavily insulated exterior walls and windows are slotted in by crane. The result is far from pretty, but the method is surprisingly safe—and phenomenally fast.(fig.10)

![Fig.10 Fixing of walls and windows](image)

5.2 Key Indicators of Sky City
• 838m height Lifts to 830m
• 6 storeys underground, 202 storeys above the ground
• Building area 1.05 million m²
• 4450 families (60m² min, 520m² max)
• 250 suites hotel rooms
• 100,000m² for school, hospital and office buildings
• Over 30,000 residents
• 93 lifts
• Some lifts directly to 173F from underground
• A street of 10 km long directly to 170F (accessible to electric cars)

• 56 column-free spaces, bigger and higher than a basketball court

• City functions as sports, entertainment, and farm & trade, etc.
  - 86,400m² vertical organic farms
  - 8,000m² open sky gardens
  - 720m² swimming pool located at 202 F
  - 100% steel structure
  - 99% PM2.5 eliminated
  - 100% fresh air
  - 20cm thermal insulated wall
  - Four-paned glass window
  - Fresh air heat recovery
  - Cooling-heating-power application
  - 3-liter water toilets and LED lights
  - Self power-generated and optimized lift service system
  - Compared with conventional buildings, BSBs are 5 times more energy efficient
  - Annual energy conservation equals 40,000 tons of oil saving, reduce CO2 emission by 120,000 tons[1].

6. CONCLUSIONS
Prefabricated structures provide high energy savings as well as are environment friendly in terms of usage. In most cases, it drastically reduces construction time and cost, and allows construction to take place regardless of environmental conditions. This type of construction is especially constructed for inaccessible areas or hilly terrain, where conventional construction is not possible. Providing for quick installation support, these structures can be developed as per the specific drawing/design plans provided by the customers. These structures are easy to dismantle and relocate. Prefabricated metal buildings not only provides superior structural strength but allows quick construction on mass scale. The Skycity in China is the best example of this.

7. REFERENCES