

Review on Study of Folded Portable Structure

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Abstract - Folded portable structure is a structure which is transportable, we can erect it from one place mount it on truck trailer and assembled to desired location. This type of structure is folded having provision of a transformation and increase their space from two sides with a desired ratio and also capable to reduce in their original area for transportation. Folded portable structure is new concept based on prefabricated structure have a vast area of study and a lot of advantage over traditional construction system. This type of architecture is easily achieving a nametag of sustainable structure but required high technical evolution to obtain proper design which is durable, repairable and creates progressively efficient use of energy and other resources. A review paper is introduced here to study the design principle and mechanism of folded portable structure with analyze numerous Folded portable structure that have been built, reviewing their achievements and deficiencies whereas reviewing their technical evolution and study to examine it on context of design principle of sustainability.

Key Words: - Folded Portable Structure, Transformable, Prefabricated, Design Principal, and Sustainability.

1. INTRODUCTION

Prefabricated folded portable structure components are manufactured in factory and assembled on site so it significantly reduced the time of construction, construction waste, and improved air quality; achieve site safety, sustainability and better quality than conventional construction method. Exist prefabricated folded portable structure are widely used for dwelling as a permanent and temporary occupation workforces involved in framing, mining, construction, military, reconstruction and residential housing unit for remote, rural and slum area. It is a best solution for emergency housing solution in disaster suffered area for the provision of medical and dwelling services to the victims. Folded portable structure designed from an assembly, that can be transported by road and airway to the site and erected to the site with minimum time with suitable mechanism and make transformation to their area by increasing or reducing it with fold and unfold. This review paper is presenting here to study the various folded portable structure that exist in the present era and analyze them in the context of sustainability, mechanism used to fold and unfold the structure and the design principle of the structure. Design principle includes structural¹, technical² and functional³ criteria which denote stability¹, rigidity¹, lightness of system², modulation and assembling between elements², transformability³ and transportability³. To study folded portable structure various components are important to study and understand which are divided into three components like moment component, load bearing structure and planar surface component. All three components are interdependent on each other and their synchronization is important to maintain its functionality and obtain folded portable structure. Here the study is focused about understanding different component, their co-ordination with each other, assembly between elements, achieved functionality in the design principle. Folded portable structure various type of model comparison is done on context of sustainability to identify eco-friendly design by considering principle of sustainability.

2. Methodology

The aim of the review is to clear the concept of folded portable structure, to improve understanding about various component of folded portable structure and their interdependency on each other, analyze various existing design of folded portable structure to find out their functionality, mechanism and design strategy and review is this structure is able to adapt the principle of sustainability or not.

The diagram present below represent the procedure to study folded portable structure.

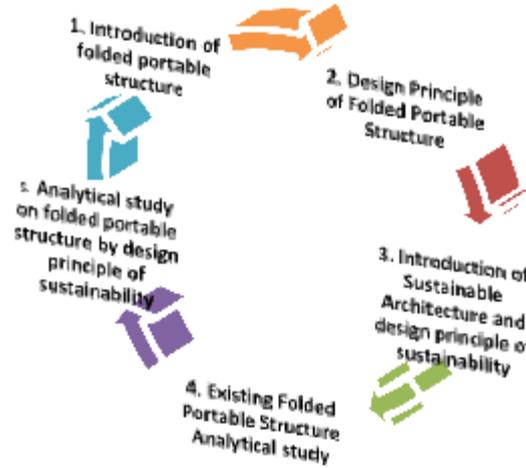


Fig 1:-procedure followed to study folded portable structure

2.1 INTRODUCTION OF FOLDED PORTABLE STRUCTURE.

Folded portable structure are prefabricated structure constructed with different type of material including steel , aluminum , plastic which are able to construct a durable structure and achieve design stability, serviceability sustainability with comfort of living being. "Folded" describe various folded connection between various component like floor, Roof, planner Connection which easily fold and unfold using movement connection and mechanism. The start force that generates the movement can be natural (human handed) or mechanical including hydraulic or rack and pinion mechanism. "Portable" includes structure which can transport from one place to another.

According to literature review of various authors In 2007 Robert Kronenburg, says that Folded "includes changing design buildings, space, form and shape by physically altering its structure, interior or skin. It is an architecture that opens, closes, expands and contracts". And portable "includes buildings that move from one place to another in order to better play its role: it is an architecture that rolls, floats or flies" (Kronenburg, 2007). Maziar Asefi, who publish in 2010 his research where he "describes a distinct class of structures consisting of rigid, or transformable elements, connected by moveable joints that can change their geometry reversibly and repeatedly and have the innate characteristic of controlled reconfiguration" (Asefi, 2010).

2.2 DESIGN PRINCIPLE OF FOLDED PORTABLE STRUCTURE:-

Study of various component of folded portable structure is divided into three component like movement mechanisms, load bearing structure and planar surface components. In terms of functionality of design, proper synchronization of all three component have to be take into consideration, to obtain proper working of the proposed design of folded portable structure.



Fig 2:-Component Divided According to Design Principle of folded portable structure

2.2.1 Movement Mechanism

Analyzing the practical, functional and stability criteria and designing a movable joint, for a dynamic connection, is an extensive and technical work. Industry catalogues have been providing mostly documentation about mechanisms connections of folded structure which having authorities' approval. In professional design of folded portable structure having understanding related to connection elements and their relation with type of movement desired to make the correct choice is important to avoid malfunction of technical design.

To understand movement connections and their mechanism various factors are important to studied.

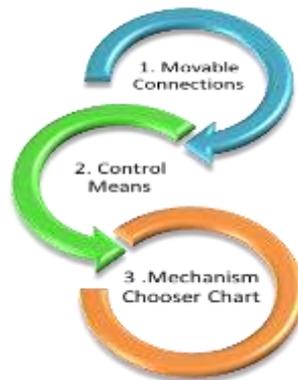


Fig 3:-Principle of folded portable structure

2.2.1.1 Movable Connection

In Folded structure, so as to allow the movement to happen, static components are associated by movable joints, changing over them into folded structure. Movement joints are not just an association between two components, it should likewise exchange loads permit relative motion in some directions while constrain in others. The types and direction of movement are connected with the degrees of freedom allowed by each joint, they derivate from the combination of the axis of the movement and the typology of movement. The first thing to observe when choosing a connection is it is self-load bearing or if it makes part of the whole structure.. Both hinged and bearing have a extend options in commercial catalogues and it's easy to find the load specification on the technical documentations.

Revolution Joints

Revolution joints are connections of hinged elements that turn around an axis have a single degree of freedom of rotation. Immense variety of hinges are available in industry catalogues and for developing specifications, some basic knowledge is needed. Besides if the hinge fits the overall design, it's important to know the axis of rotation, the load that the hinge must stand and it relation with size and material and the angle of movement. These first specifications are probably the most important; the load can determine the number and size of joints needed, and the axis the necessity of angle and torque control.



Fig 4: - Revolution Joints

Bearings

Bearings containing fluids to separate the surfaces of contact are used to reduce friction between connections.

| Types of bearing | 1.sliding bearing | 2.roller bearing | 3. Common bearings |
|--|--|---|--|
| Applied use in folded portable structure | Support high loads with high speed revolution and are impact-resistant, noise-absorbent but with higher degree of maintenance. | Intermediary elements to transfer forces, requiring lower lubrication and maintenance, but they are susceptible to impact damage. | translation movements with the basic principle of wheel-rail systems |



Fig 5:- Sliding Bearing



Fig 6: - Roller Bearing

2.2.1.2 Control Mechanism

Control mechanism is responsible to perform motion in a stable body and give it dynamic movement. Connection give in between folded portable structure control the dynamic movement of structure by adjusting its force and speed and changing direction of movements Control means include sliders, gears, pneumatics, actuators, hinges and linkages.

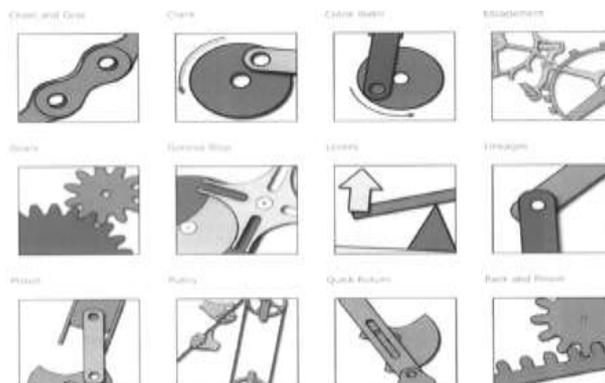


Fig 7:-Examples of Control Means Types

In 2012 Author (Schumacher) divided control mechanisms of this type of dynamic structure in four main types of simple machines.

1. **Rope and rod**- allow rigid objects to be pushed or pulled using a rope and bar, applying the same amount of force in the same direction but at a different point.
2. **Rope and pulley**- direction of the force can be changed
3. **Lever**- allow to change the magnitude of the force
4. **Inclined plane**- change magnitude of force.



Fig 8:-Examples of Control Mechanisms Machines

2.2.1.3 Control Mechanism

To correlate the relation between mechanism and motion with type, direction and force of movement the present chart are followed.

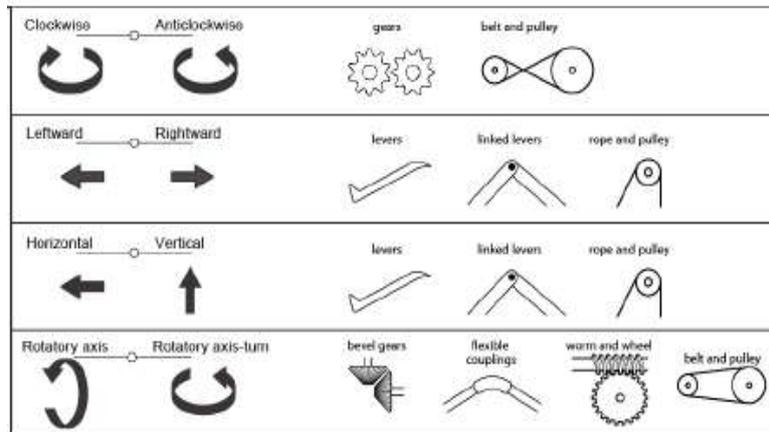


Fig 9:-To Change Direction of Movement

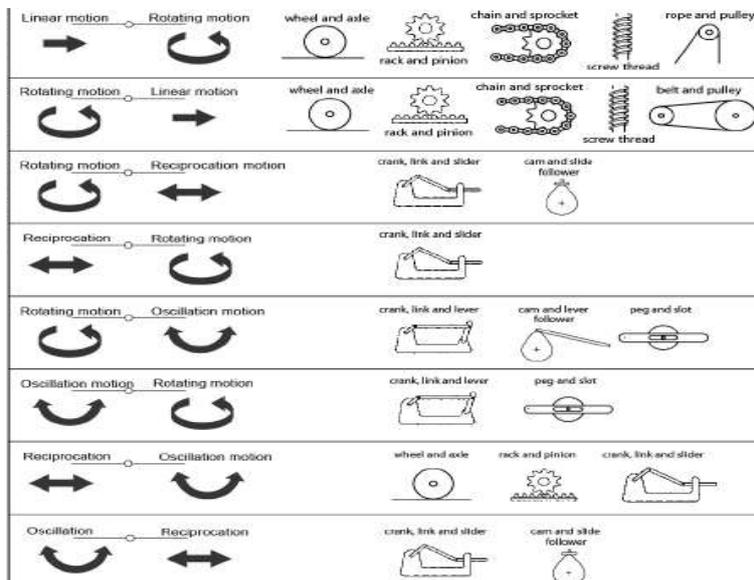


Fig 10:-To Change Type of Movement

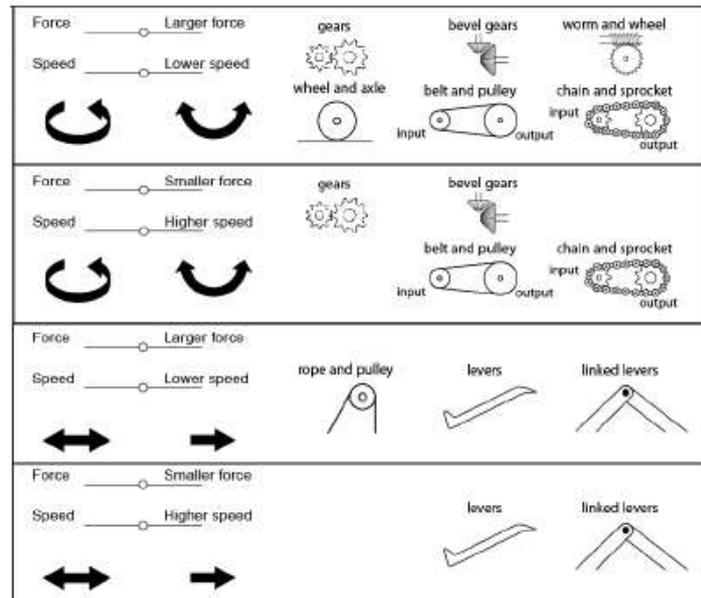


Fig 11:- To Change Output Force and Speed

2.2.2 Load Bearing Structure's

Unlike static structures, the requirements of portable dynamic structures differ because movements are necessary and are part of its conversions, and issues such as stiffness, stability and resistance must not be simply addressed, but controlled. Stability is essential both in its "closed" and in its "open" positions (Schumacher, 2010). But to achieve transformation process folded kinetic structure need support machinery during movement. This generates high operating costs and compromises more easily a long-term operation of mechanisms and connections.

Focused on transportation methods of dynamic folded structure; it restricts the dimensions of the folded building and the overall weight. If the buildings include auxiliary lifting points and vehicles are needed to promote displacement, the structure has to resist the stress generated by the movement. Considering the foundations is also an objective, it's important to have the perfect level in the structure for the proper occupancy and the correct function of mechanisms. The mobile architecture can be placed in different locations with different contexts, and it is important that the foundation is flexible enough to adapt without improvisations.

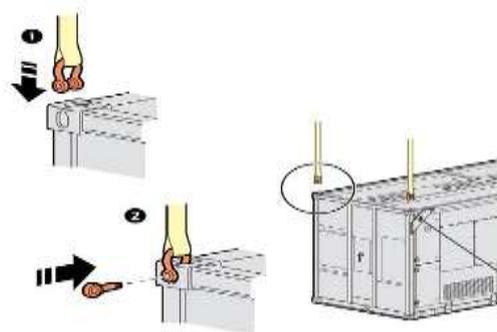


Fig 12:- An example of corner lifting points in containers

Folded transformable structure, need to be capable to bear the load in three different moments:

1. **The close position**- usually when transports also occurs and it has to be stable during lifting and displacement;
2. **The opening position**- when transformation is taking place and structure is not stable;
3. **The open position**- where the transformation has been completed and components are locked in place and the stable structure is once again reached.

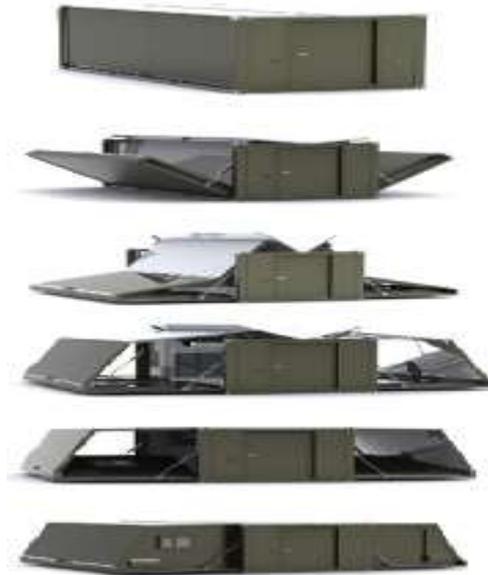


Fig13: - Deployable positions of transformation of folded portable structure

2.2.2.1 Dynamically Self-erecting Structures

The mechanism to achieve Dynamically Self-erecting Structures is the use of linked, folding supports in a cross-cross “X” pattern, known as a pantograph (or scissor mechanism) OR lever arm based structure. The motion is achieved by the application of pressure one side to deployed it to other side, elongating the crossing pattern, and propelling the structure in the deployable direction is depend on design of structure. The direction and form of the deployed structure can be defined by the angle and position of linkage between the bars. The most difficult point is to determine how much of opening each scissor will realize, how to achieve the precision needed at the end of deployment for the structure be perfect connected and stable. The movement of the scissor action can be hydraulic, pneumatic or mechanical (via a lead screw or rack and pinion system) and with the right control, specifications and leveling in site these applications can, not only put the structure in motion, but also control the opening of each mechanism.



Fig 14:- Deployable Folded Portable Structure manufactured by tenfold engineering based on scissor mechanism.

2.2.2.2 Expandable Folded Portable Structure

Expandable architecture refers to an architecture transformation which fundamentally affects the whole building form and where the components parts are pre-hinged and continuous, and remains so through transformation (Zuk and Clark, 1979). This can be also the characteristics of kinetic components and self-erecting structure, but the major difference is that in expandable architecture the basic elements are connected at all times and depend of each other to achieve transformation. Be sides these, this architecture may be referred as “expandable” and takes advantages of the combination of rigid and deformable elements for construction.

Pre-hinged construction systems, usually with a kit form of auxiliary parts. Folding mechanism is commonly used in this system. A notable advantage is the little depth or thickness in transportation, being able to transport a larger quantity in a same vehicle. As the building is unfolded, the structure is also unfolded and within the envelope, it’s unstable and there is

the need of auxiliary equipment. Once the unfolding process is completed, and the fixations and locks realized, the rigid elements have a load bearing capacity and are stable

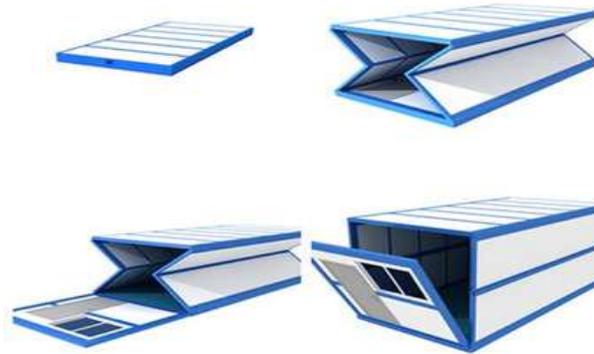


Fig 15:- Expandable Folded Portable Structure

2.2.2.3 Piers and Foundation

The fixations and foundations of folded portable structure are probably the crucial part of a structure project. The correct leveling of the building is what can determine the correct function of connection mechanisms and mobile components for being transportable; a project needs to foresee the different location sites and possibilities that the building may encounter in throughout its life. There are multiple options when choosing piers and foundations, and all depends on the project and soil conditions of the terrain, but a few basic recommendations can be made.

Base Pads

Base pads are used as a base plate to eliminate deflection and preventing the piers and foot of sinking into the ground. The size of a pad is directly related with the item it supports, material and variation of load capacities. In the commercial catalogue is possible to encounter pads with different materials that are light-weighted and low dimensioned, which favors the relocation and reuse(Figure 65). For piers are used plywood, metallic and ABS pads; for footing are used metallic and plastic; nevertheless, the more advertised and commercialized is the plastic and ABS bases, reassuring the lightweight properties and the capability of absorbing vibrations.

Piers and Footing

The principal differences of piers and footing are the load, the height and time of use locations- for faster relocating buildings, the footing system are easier to use . But booth should use the screw jacks mechanical devices to lift and leveling the buildings. The “jack” employs screw thread or hydraulic cylinder to lift heavy loads and apply great linear forces. Normally, screw jacks are simple mechanisms that need to be manually operated until reaching the grading desired, they can reach high load capacity (1.5 – 3tons) and, when threaded, high height (24 inches) . Although, they are not recommended for buildings that need complex grading adjustments because of the difficulties of an accurately assemble and risk situations for workers. They have great use for foot of buildings and kinetic components, in this last case, they can be an auxiliary support for the frame structure and help to lock the components in place.



Fig 16:-Base Pads



Fig 17:- Piers

2.2.3 Planar Surface Components

Surface elements of folded portable structure representing the active layer and inquiring the specifications necessity of covering materials, sealing joints and installation system in a structure and their relationship to the whole as: site, structure, skin, services, space plan, and stuff. structure is the load bearing elements, foundation and skeleton; skin is the exterior surface, such as siding and windows; services are the nervous systems of a building, such as its heating plant, wiring, and plumbing; space plan includes walls, flooring, and ceilings; and stuff includes lamps, chairs, appliances, bulletin boards, and paintings (brand, 1994). A good strategy to achieve this is to reduce the assembly parts, by using better specific materials that fulfill more performance requirements. Reducing assembly time and cost depending on methods and processes with a faster implementation and a less potential to failures

Material

Covering materials in this type of building should not only perform properly as enclosure, but they should also resist repeated movement and environmental changes before, during and after transformation (Asefi, 2010). Also, the skin contributes to the self-weight of the construction and in the dimensions of movable elements (Schumacher, 2010) and light-weight materials should be considered at all times. Industry offers a variety options with different resistance and rigidity characteristics and the shape alterations of the cover components need to be think of since the beginning of the project. Is the skin stable and moves with the structure, or is it flexible and cover the structure as it moves? Many factors of materials characteristics like Translucency, Fire,. Water-proof mechanical resistance, cleaning, insulation is important, recycling.

2.3 INTRODUCTION OF SUSTAINABLE STRUCTURE AND DESIGN PRINCIPAL OF SUSTAINABILITY.

Introduction of Sustainable Structure:-

Sustainable structure is the practice of creating structures using resources that are environmentally responsible and energy-efficient. It encompasses factors such as internal and external design, construction, operation, maintenance, renovation, and deconstruction. The aim of sustainable building design is to reduce the overall impact of the built environment on human health and the natural environment (Anonymous, 2014a).This design practice emphasizes efficiency of heating and cooling systems; alternative energy sources such as solar hot water, appropriate building siting, reused or recycled building materials; on-site power generation - solar technology, ground source heat pumps, wind power; rainwater harvesting for gardening, washing and aquifer recharge; and on-site waste management such as green roofs that filter and control storm water runoff (Yan and Stallions 2006). Sustainable building is the practice of creating structures using resources that are environmentally responsible and energy-efficient. It encompasses factors such as internal and external design, construction, operation, maintenance, renovation, and deconstruction. The aim of sustainable building design is to reduce the overall impact of the built environment on human health and the natural environment (Anonymous, 2014a).

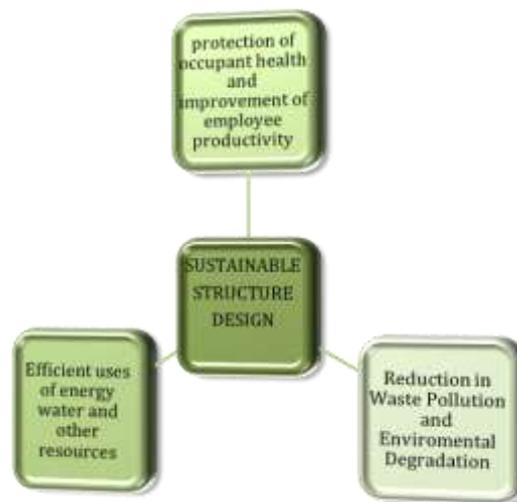


Fig 18:- Main goals for sustainable structure design (Anonymous, 2014a)

Design Principal of Sustainability

- 1. Optimization of resources (natural and artificial):** Structure that use natural durable, reclaimed and re-usable materials and resources can be designed.
- 2. Reduction of energy consumption:** Designing bioclimatic buildings, having energy efficient construction solutions that use natural energy sources and local materials. Reducing transportation of materials.
- 3. Utilization of alternative energy sources:** Buildings using wind, solar and geothermal energy as passive-active integrated systems can be designed.
- 4. Reduction of waste and emissions:** To reduce and manage the pollution and waste, it can be used waste products, putrescible and non-polluting materials.
- 5. Improving people’s health and wellbeing:** Fulfilling people’s social life and relations and enhancing their life quality, using of healthy materials, providing natural ventilation.
- 6.Reduction of building costs and maintenance:** To reduce price and maintenance buildings having extended life cycles and technological solutions can be designed, by using reclaimed and re-used materials

2.4 EXISTING FOLDED PORTABLE STRUCTURE ANALYTICAL STUDY

1. TEN FOLD STRUCTURE

| | |
|-----------|---------------------------|
| System | Pantograph hybrid |
| Structure | Dynamically self-erecting |
| Architect | David Martyn |
| Company | Ten Fold Engineering |
| Year | Patent 2012 |
| Location | United Kingdom |
| Use | Stage |



Fig 19:-Ten Fold Structure

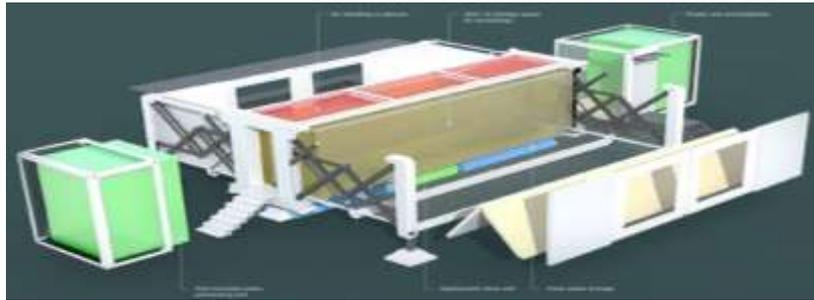


Fig 20:- Assembly of Ten Fold Structure



Fig 21:- Transportation System of Ten Fold Structure

| TEN FOLD STRUCTURE COMPONENTS |
|--|
| <p>Movement Mechanisms</p> <p>Deployment in 8 minute with 10 persons pin-jointed linkage of lever arm(Scissor) with walls that perform specific useful moment repeatedly, precisely and reversibly in such a way that they can fold up, including folded roof and floor with each element counterbalancing the other so that very little power is needed to drive them</p> |
| <p>Load Bearing Structure</p> <p>It uses a double single scissor {Lever Arm} All the linkage can be driven by almost any one of the individual bars of the linkage by using hydraulic or rack and pinion mechanism. This gives them extreme versatility and flexibility in all application are obviates the need for complex locking and feedback system.</p> |
| <p>Planar Surface Components</p> <p>75-120mm free finished composite panels</p> |

| Transformable Design Strategies | |
|--|--|
| Design | |
| Expansion and Flexibility | Expanded counterbalance mechanism from two side due to hydraulic mechanism and lever arm reliably |
| Compactability and Transportability | 64m ² of flexible, ready-to-use space delivered in 8 minutes from a standard truck The Module expands upwards and outwards simultaneously providing 32m ² of additional floor space |
| Structural Stability and Deformability | Stable at all times |
| Architectural Obstruction | The interior is used for storage of movable components Moveable internal walls and Exchangeable pods t |
| Operating System | Automatic using hydraulic mechanism. |
| Construction and Operations | |
| Reliability and Safety | The units are easily customized and readily adaptable to user and site Specifics. All units and their related Pods are modular, interconnect able and interchangeable and provide high quality, flexible space and facilities for living and working to suit user and site specifics in almost any environment or working sector |
| Manufacture and Shipment | industrial constructions under prefabrication premises |
| Life-Expectancy | TEN FOLD units are robust and resilient, long-life, well-insulated buildings designed to be moved and moved again but with the designed performance characteristics expected of a solid building. The units <i>can be</i> built to international standards and designed to comply with the broadest ranges of local construction codes |
| Capital Cost | 129000 dollar |

2.5 STUDIE ON FOLDED PORTABLE STRUCTURE BY DESIGN PRINCIPAL OF SUSTAINABILITY

1. Optimization of resources (natural and artificial):

Tenfold Structure use durable, reclaimed and re-usable materials and resources and designed as a prefabricated structure.

2. Reduction of energy consumption:

Tenfold is designed as a prefabricated structure constructed in factory so reduce and minimized construction waste and reduce transportation cost and save land as foundation are not stuck to ground.

4. Reduction of waste and emissions:

Conventional building contributes to CO2 emission prefabricated structure with composite material panel reduce Contribution to emission and help to maintain ecological parameter balance

5. Improving people's health and wellbeing:

Tenfold structure provide comfort, luxurious life to the people by designing are able to done with peoples requirement and have ability to maintain people healthy

6.Reduction of building costs and maintenance:

Cost of structure is high with low maintenance cost.

3. CONCLUSIONS

Folded Portable structures are a vast field of study, and each of the subjects cover in this research can be explored to study the basic concept of this type of type of structure and to study about sustainability principle and state that prefabricated structure has more capability to attain sustainability as compared conventional structure.

Here the component of folded portable structure with their mechanical and movable connections properties and the relation with the structure and the movement realized can be studied. And with that study, analysis of existing ten folds structure are done on various parameters with the checking of it sustainability. This research aims to evaluate the technical means of a structure transformation of folded portable structure and design decisions required for it success. In order to better explain transformation from this technical perspective.

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