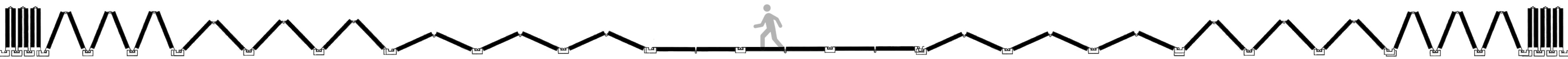
AN INSTANT CONNECTION

[designing an emergency, deployable bridge]



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P2 Presentation | Graduation Plan

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[CONTENTS]

Abstract

1. Introduction ...03

1.1 Problem Statement

1.2 Research Objectives

1.3 Research Question

1.4 Scope of Research and Process

2. Concept ...09

2.1 Concept Development

2.2 Requirements

2.2.1 Functional

2.2.2 Geometrical

2.2.3 Design

2.3 Design Strategies

3. Modularity ...15

3.1 Definition

3.2 Standard Components

3.3 Modularity in Architecture

3.4 Advantages and Disadvantages

4. Deployability ...21

4.1 Definition

4.2 Advantages

4.3 Design Principles

4.4 Deployable Systems and Types

5. Materiality ...27

5.1 FRP

5.2 Advantages

6. Design ...31

6.1 Preliminary Design

6.2 Final Design

6.3 Detailing

6.3.1 Superstructure

6.3.1 Substructure and Connections

6.3.2 Deck

6.3 Drawing and Visualizations of Final Design

5.5 Transportation Process

6.5 Erection Process

7. Structural Calculations ...

7.1 Structural Analysis

7.2 Loads and Load Cases

7.3 Finite Element Analysis

7.4 Optimization of Structure

7.5 Structural Evaluation

8. Manufacture ...

Literature

9. Conclusions ...

9.1 Conclusions

9.2 Recommendation

9.3 Improvements

9.4 Further Development

[ABSTRACT]

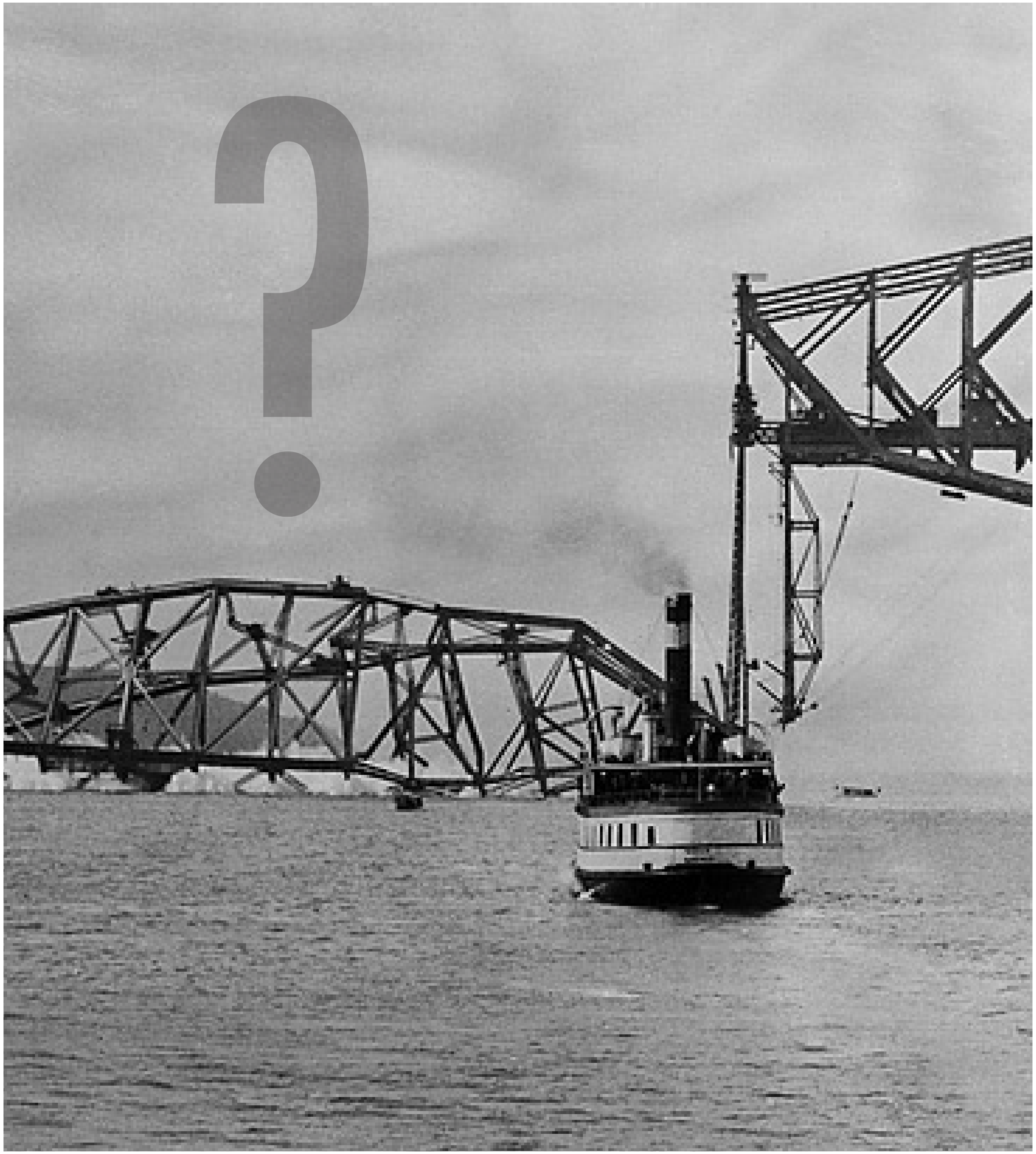


Figure. 1| Quebec Bridge, Canada
The Quebec Bridge is a road, rail and pedestrian bridge across the lower Saint Lawrence River to the west of Quebec City in Canada. The project failed twice, at the cost of 88 lives, and took over 30 years to complete. Due to a design flaw the actual weight of the bridge was heavier than its carrying capacity, which caused it to collapse twice, first in 1907 and then in 1916, causing 95 deaths.
The Quebec Bridge is a riveted steel truss structure and is 987 m (3,239 ft) long, 29 m (94 ft) wide, and 104 m (340 ft) high.
[source: http://www.engineeringcivil.com]

Extreme events, including natural disasters such as typhoons, floods, tsunamis and earthquakes as well as man-made like terrorist attack have become the largest disaster around the world over the years. Their impacts can be calamitous devastating entire countries overnight and making millions of people to suffer.
Due to the above disaster, some roads and bridges were damaged resulting in isolated of residential communities, and the inability to deliver emergency relief supplies. In order to provide quick help, an easy transported and rapid installed temporary bridge becomes critical for the transportation of the people and the delivery of food and medical supplies by emergency vehicles to the disaster area.
This graduation research seeks to the design of "*an instant connection*" as an "out-of the box" solution for single-lane prototype bridge that has a span length that varies according to the specific needs. The instant connection is a deployable- both transportable and transformable-, lightweight bridge. The bridge is going to make of identical FRB prefabricated elements relying on the term of modularity. The whole process of modules construction and the final assembly realizes off-site (in the factory) and the completed bridge is transported on-site in a compacted form thanks to its deployable capability. Finally, it is installed on-site in a limited time and special equipment for short term, servicing the emergency needs. After the bridge mission completed, the bridge can be packed and reused in another emergency call.

Keywords:
emergency
temporary
deployability
transportation
transformation
modularity
FRP

1. INTRODUCTION

1.1 Problem Statement

1.2 Research Objectives

1.3 Research Question

1.4 Scope of Research and Process

1.1 Problem Statements

“*Mayday, Mayday, Mayday- Bridge down*”.

Every year severe floods, storms, hurricanes but also explosions and terrorist attack cause immense suffering for millions of people around the globe. When disaster strikes, whether natural or man-made, helping the victims quickly is vital important but a lot of times can be severely hampered, especially in cases that infrastructures are destroyed and transportation network is interrupted.
We know that we cannot underestimate the importance of emergency planning. If an earthquake or terrorist attack hits, we won’t necessarily have advance alerts or opportunities to double- and triple-check our plans. We cannot stop these kinds of disasters but we can arm ourselves with the necessary equipment in order to interface them.
Part of the plan is the design and construction of emergency bridges to reconnect communities, offering replacement of the collapsed bridge or an alternative emergency escape providing an un-interrupted access to the effected area.
In an emergency case, the conventional bridge construction techniques, which are made on-site in a slow construction process, are based on all-in-one communications management unit- integral design and they require large transport vehicles and specialized workers, are not suitable. The de-

1.1 Problem Statement

In Taiwan, 88 floods were caused by the Morakot typhoon in 2009. During that more than 200 bridges were damaged and more than 100 bridges were washed away. Chi-Chi earthquake in 1999 also caused more than 150 bridges damaged, resulting in isolated mountain communities, to which emergency relief supplies could not be easily delivered. [Yeh, 2012]

Figure 1.1: Bailey Bridge
The Bailey bridge is a type of portable, pre-fabricated, truss bridge. It was developed by the British during World War II for military use.
A Bailey bridge had the advantages of requiring no special tools or heavy equipment to assemble. The wood and steel bridge elements were small and light enough to be carried in trucks and lifted into place by hand without requiring the use of a crane. The bridges were strong enough to carry tanks.
[source:http://en.wikipedia.org/wiki/Armoured_vehicle-launched_bridge]

Figure1.2: Armoured vehicle-launched bridge(AVLB)
Nowadays, the emergency military bridge structures employ sophisticated structures made up of few modular large components, designed and fabricated using advanced materials and launched using variety of techniques (automated construction techniques, remote vehicle control, teleportation and fully autonomous bridging systems all offer operational benefits are in the military field). The modules typically weight 1,5tonne each, precluding manual construction and are made of specific strength materials and mechanizations. In general, military bridges are essential for good mobility and the evolution of the bridge structures. . [Escrig and Brebbia, 2000]
An armoured vehicle-launched bridge (AVLB) is a combat support vehicle designed to assist militaries in rapidly deploying tanks and other armored fighting vehicles across rivers. The AVLB is usually a tracked vehicle converted from a tank chassis to carry a folding metal bridge instead of weapons.
The bridge layer unfolds and launches its cargo, providing a ready-made bridge across the obstacle in only few minutes. Once the span has been put in place, the AVLB vehicle detaches from the bridge, and moves aside to allow traffic to pass. Once all of the vehicles have crossed, it crosses the bridge itself and reattaches to the bridge on the other side. It then retracts the span ready to move off again. AVLBs can carry bridges of 19 meters or greater in length.
[source:http://en.wikipedia.org/wiki/Bailey_bridge]


Figure 1.1: Bailey Bridge


Figure 1.2: Armoured vehicle-launched bridge (AVLB)

sign must follow the rules of emergency, which in contrasted to conventional ways are based on off-site prefabrication, quick and easy transportation and installation process without any specialized equipment.
Case studies for previews and existing designs show that the emergency bridges are using neither large numbers of small components assembled and dismantled by hand such as Mabey and Bailey [figure 1.1] nor fewer and larger components with special mechanisms reducing build time and manpower bridges like most of the military emergency bridges [figure 1.2]. The above two examples are investing either in time (speed) creating structures that can be able to install in just few minutes or in simplicity during transportation and erection. So far, the concept of an emergency bridge is distinguished to high mobility with small units or rapid assembly with large units. However, in an emergency situation the combination of the above two requirements is essential.
By studying these cases, we sought to identify and expand on lessons learned, address which actions did and did not work well given the circumstances of the incident, and incorporate lessons into the emergency response plan for bridges.

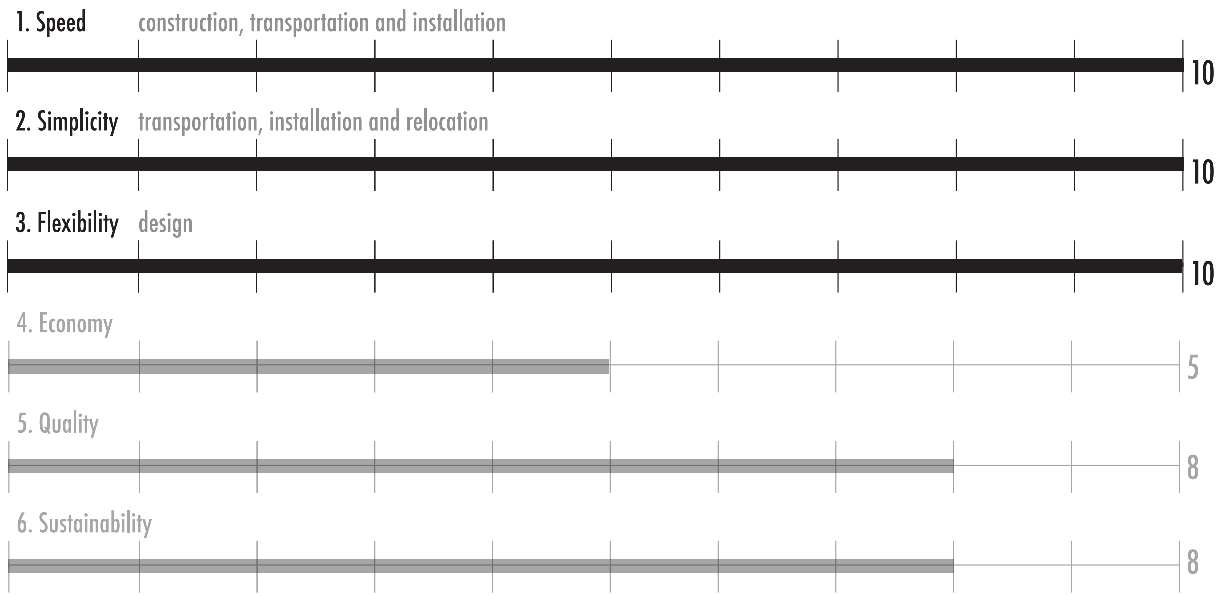


Figure 1.3: Design and General Objectives

1.2 Research Objectives

1.2 Research Objectives

According to the problem statement, the two main requirements, which will define the proposal design are:

1. Speed in Constructiob, Transportation and Erection (time)
2. Simplicity in Transportation and Erection (effort)

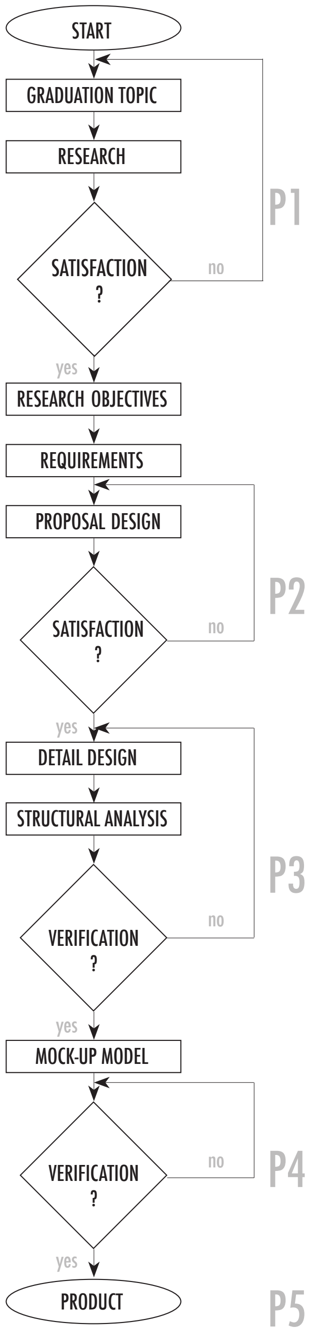
However, there is another (third) characteristic,which is important in the design of a prototype bridge:

3. Flexibility in Design

The research objectives are divided in two. The first part refers to main design objectives (speed, simplicity and flexibility) and the second one to the standard product objectives (cost, quality and sustainability)

1. SPEED: The main goal is to achieve an instant bridge structure, which is intended to provide rapid solutions in an emergency situation by providing help. The speed has to deal with the construction phase but mainly the transportation and erection.

2. SIMPLICITY: The design has focused on research and development of an emergency bridge, easy to transport, erect and relocate.



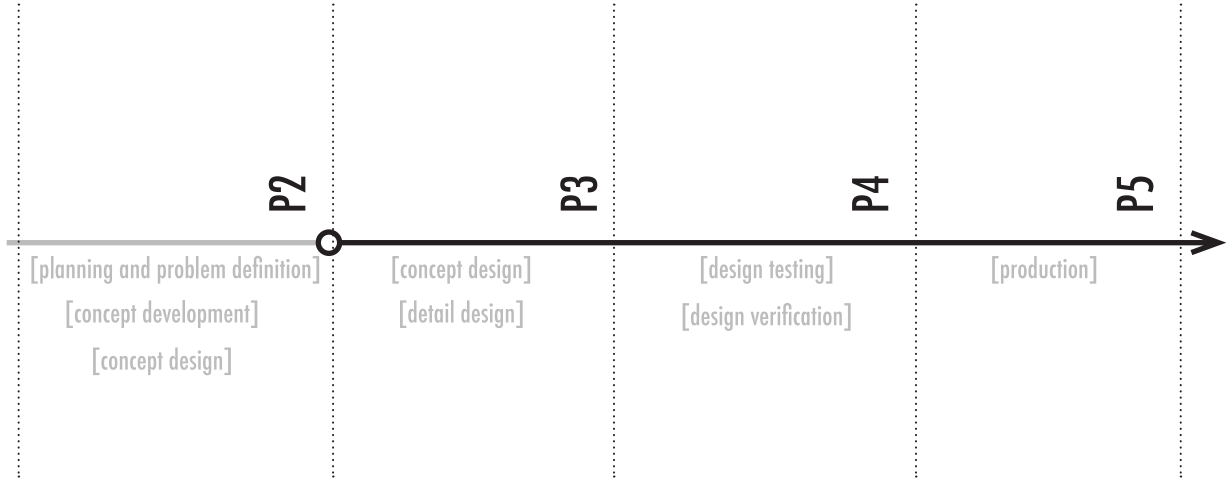


Figure 1.4: The Six Steps of Product Development Management and its relation to the graduation process (P)

Figure 1.5: Programming the graduation process

3. FLEXIBILITY: The bridge must be adaptable in design with multiple span configurations to provide flexibility of use in a wide range of emergency applications.
5. COST: The cost refers to the cost of the material, construction and installation. Though the idea of an instant connection seems “cheap”, the initial cost is relatively hight, because of the special requirements that must be raised.
4. QUALITY: Although the bridge is applied for temporary purposes, it must follow the requirements of safety, reliability and precision providing structural strength, stiffness and stability. Durability is a key criterion, as the structures are often used for periods far exceeding their initial planned duration and they are reusable.
6. SUSTAINABILITY: The sustainability is translated in energy safe during transportation and installation process (speed and simplicity in both phases) but also the material save, as it will be explained later in chapter 3.

1.3 Research Question

How a bridge can be fast, simple and flexible constructed, transported, installed and uninstalled, servicing the needs of emergency?

Regarding the above quote, the design must follow the below sequence,
1. Speed
2. Simplicity
3. Flexibility

in all of the six production phases: design, construction- assembly, transportation, installation, use and relocation.

1.3 Research Question

1.4 Scope of research and Process

1.4 Scope of Research and Process

The proposal framework process of my graduation thesis feeds on the Six Steps of Product Development Management according to Urlich and Eppinger [Urlich and Eppinger, 2004]:

0. Planning and Problem Definition: In this preliminary step, project mission statement (problem statements), target group, research objectives, key assumptions, constraints, requirements and design rules must be clarify. [P2]

1. Concept Development: The activities of the concept development phase include the selection of the technological working principles of the product in order to best meet current needs and the choice of architectural approach. [P2] These requirements are afterwards transformed into technical solutions.

2. Concept detailing: The concept-detailing phase includes the development of the conceptual product architecture. [P2-P3]

3. Detail design: This step includes specification of materials, geometry and tolerances as well as details related to the construction, assembly, transportation and erection. [P3]

4. Design verification- Testing: The product improvement and refinement phase includes extensive testing, validation and optimization in all levels. It involves assembling and testing prototypes through different scale of mock-ups and implementing any required changes to the designs. For this step, finite elements analysis (FEA) will be also used. The aim of FEA is to provide a satisfactory numerical model that accurately predicts mechanical behaviors such as deflection and strain. The numerical analysis was carried out using the general-purpose finite element analysis software DIANA. [P4]

5. Production: Finally, a mock-up in scale 1:2 (or even 1:1), of part of the structure is going to be made, visualizing the product. In a further development, tests and improvements in a 1:1 mock-up will finalize the bridge design. [P5]

The research has been configured as an invention on a novel emergency bridge focusing on the design, assembly, transportation, erection and relocation processes. The structure will be designed, tested and visualized through drawings, structural analysis and mock-ups.

2. CONCEPT

2.1 Storyline

2.2 Requirements

2.2.1Functional

2.2.2 Geometrical

2.2.3 Design

2.3 Design Strategies

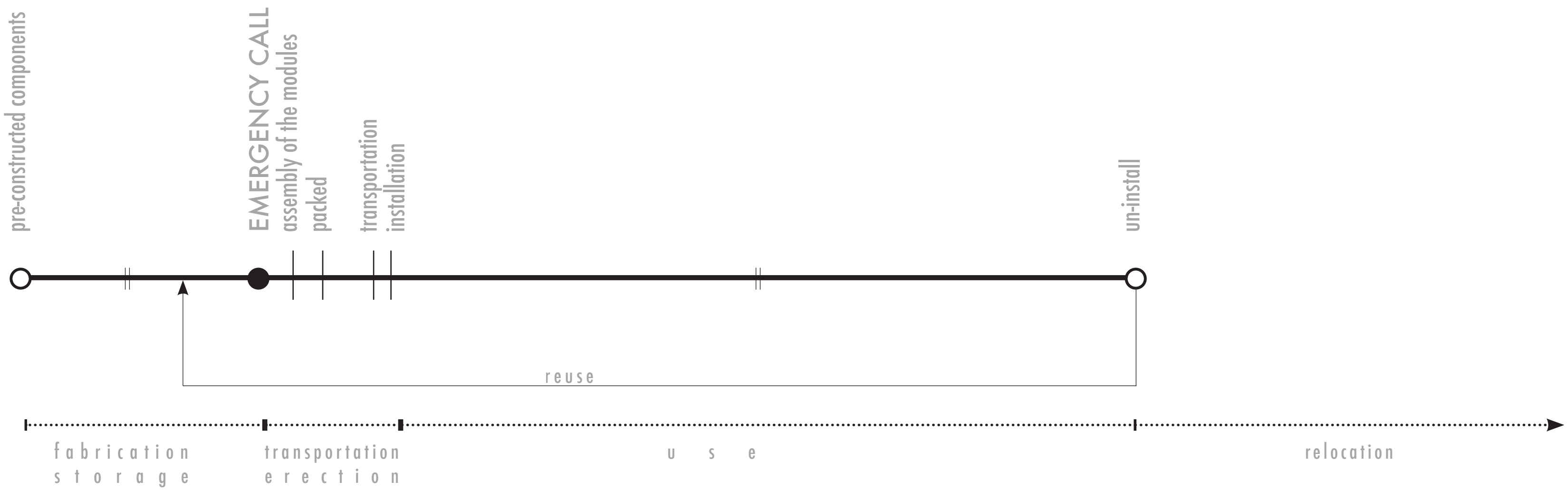


Figure 2.1: Visualization of the time line

2.1 Storyline

The bridge can be erected when a flood, hurricane, tsunami or any other disaster, destroys the existing infrastructure or as an alternative escape and connection in an emergency need.
The basic idea is based on the design of a structural component that is fabricated off-site. The pre-constructed components will be storage and when there is an emergency call, a number of modules, according to the situation, will be assembled and the completed bridge will be ready to transport. Because of need of speed and simplicity, the erection will be realized in few hours by locals or unskilled workers using simple equipments such as crane. The temporary bridges will be used to cross rivers, canals or any other obstacles just after the disaster, until a new permanent bridge is constructed or the old one is repaired or until there is not any more the need of emergency connection. Finally, the temporary bridges will be uninstalled and packed to be ready to reuse in the next emergency call.

2.1 Storyline

2.2 Requirements

The requirements of the bridge design are divided in three categories. Firstly, the functional requirements, which are related to the capacity and the usage of the bridge, then the geometrical requirements, which are more technical and finally, the design ones according the the research objectives.

2.2 Requirements

Figure 2.2: Functional Requirements

1. Functional Requirements

It is important to clarify what the bridge does, from the first steps of the research. In short, what function- use, capacity and purpose, it serves.

1.1 Usage: The designed bridge will serve emergency situations either as replacement of the existing bridge or as an alternative emergency route. This solution is a temporary, just after the disaster for short term, until the former bridge is being to repair or replaced or until the emergency need is recovered. The bridge is going to help the victims (emergency escape) and get drinking water, food, medical assistance and shelter.

1.2 Capacity: As an instant connection for emergency calls, the bridge is going to serve people and “emergency vehicles”. An emergency vehicle is any vehicle that is designated and authorized to respond to an emergency like police and security, fire and rescue or medical.

1.3. Structural Principles: There are several loads that the bridge must support. Except of the dead loads of the self-weight, we have to consider also the live loads such as the vehicle and pedestrians weight but also the wind and earthquake loads and the thermal effect, especially in case of natural disasters, when the extreme events such as fire or tornado will be possible. The emergency vehicles, that are mentioned above, will have speed and weight limitation, 30km/h and 75000kg respectively. The bridge, as a single-line but both directional, will have an extra limitation, that only one vehicle is allowed on it.

Although it is a temporary solution, the structural strength, durability, robustness and low maintenance feature also important in design configuration.

2. Geometrical Requirements

2.1 Dimensions

2.2 Components

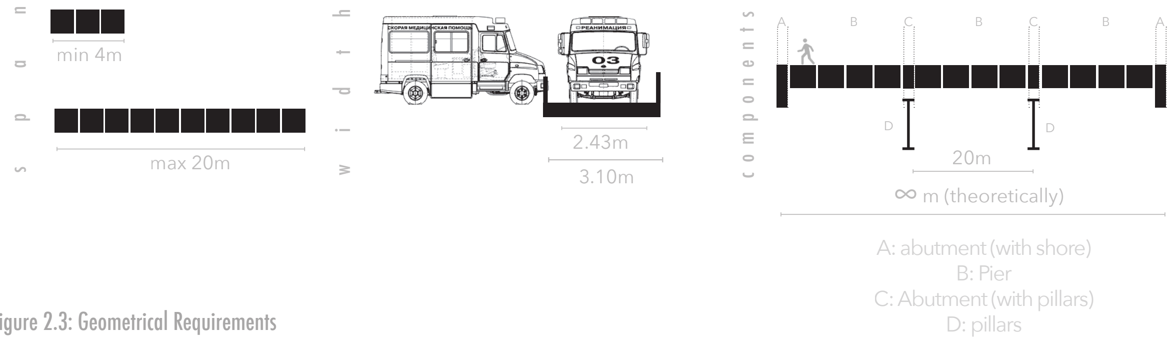


Figure 2.3: Geometrical Requirements

2. Geometrical requirements

Some of the geometrical requirements are following the Design Manual for Roads and Bridges (DMRB) however; in an emergency bridge the functional requirements (usage and capacity) will define the geometric ones.

2.1. Dimensions:

2.1.1 Span: As a bridge has a prototype character, it has to be able to bridge different spans creating various solutions. This span varies from 4meters to 20meters . Although, the span of 20meters is set as a maximum limitation, pillars can be applied every 20meters by covering even larger spans.

2.1.2 Width: The bridge is a single-line and according to the “emergency vehicles” requirements (Fire vehicle has 2.40 meters widths, plus 0.30m from both sides= 3.10 meters) its total width has to be 3.10 meters.

2.1.3 Railings: The minimum height of pedestrian railings has to be 1200mm (42 inches) above the top of the sidewalk.

2.2 Components: The bridge consists of three main components. Extra parts must be avoided saving time during erection. The bridge consists of a beam, as called superstructure and a substructure, which absorbs loads from the superstructure and transformers them into the ground. The substructure includes the abutments, which mark the bridge end points and transition into the ground and the central support such as piers and pillars. [Keil, 2013]

A & C. Abutment: Because the site’s foundation soil is unknown and most of the time brittle the

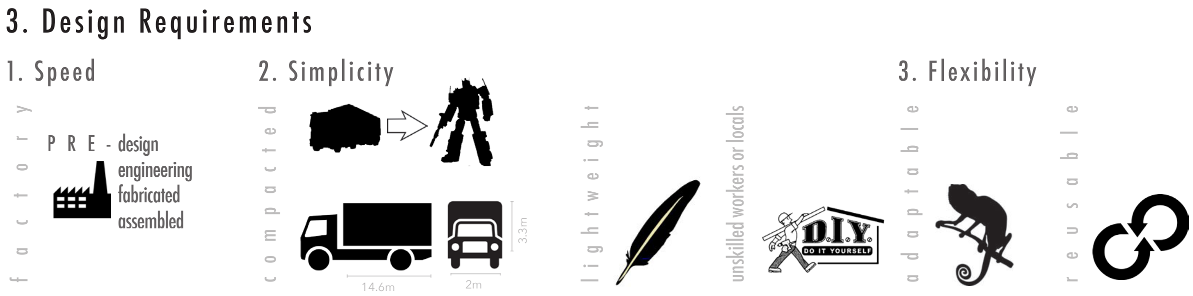


Figure 2.4: Design Requirements

2.3 Design Strategy

connection with the shore become an important issue. Consequently, the abutment (it is the portion of the bridge that supports the end of the bridge span providing lateral support for approach roadway- anchor points have bigger internal forces) has to be designed and tested separately.
In case of intermediate support- pillar, the abutments have to design separately, providing the ability of connection between two of them.
B: Pier: The pier is the portion of the bridge between abutments, providing intermediate support of the superstructure and the foundations and it is the main structure.
D: Finally, the pillars are used only in cases where the span is bigger that 20m. (For the current graduation, the span of 20meters will be design and tested and the idea of the extended ability will be postponed for further development)

3. Design requirements

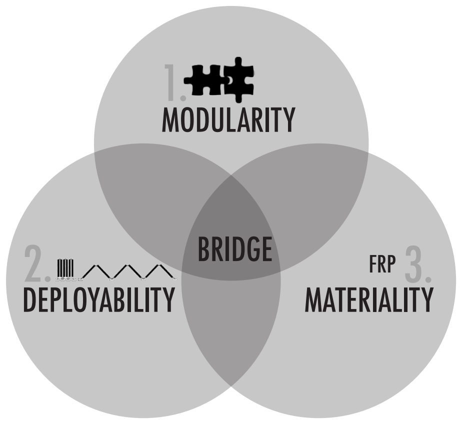
According to the problem statement, the research question and objectives, the three main requirements, which will define our proposal design, are: speed, flexibility and simplicity. These three characteristic are generating certain design requirements.
3.1 Pre-completed: As the time factor (speed) is crucial in emergency case, the bridge has to be pre-design, pre-engineering and pre-fabricated (saving time). The elements will be constructed and assembled in the factory (off-site manufacturing process) and then transported and installed in a limited time. As a result the structure has to be pre-constructed and pre-assembled achieving the

speed in transportation and installation.
3.2 Compacted form: The bridge has to be a compact structure for easy transportation and installation without help from heavy equipment to be innovatively creating an instant connection. The complete bridge with all components should fit in one standart size truck (Truck dimensions: 14.6m (48feet) height x 2m(8'6'') width and 3.3m(13'6'') height).
3.3 Lightweight: The structure has to be as lightweight as possible for easy transportation and installation.
3.4 Locals: The mechanism for erection, dismantling and relocation must be easy understandable by unskilled workers or locals.
3.5 Flexibility: Adaptable design, which will be able to bridge different configuration by adding or subtracting elements, providing Variable Gap-Crossing applications.
3.6 Reusability: As a temporary structure it has to by able to re-installed and reuse.

2.3 Design Strategy

The next three chapters are giving fundamental descriptions regarding three key features of our bridge structure design: Modularity, Deployability and Materiality.
As we will see later, to the further analysis of each term, there is no doubt that these three terms can be combined efficiently covering the above requirements of the emergency bridge. The terms Modularity and Deployability are inextricably linked and in combination with a selection of a proper material can offer the promising solution.
Firstly, the term modularity is described and analyzed, since the bridge will consist of a standard-base, pre-fabricated, repeatable modules, which can create different length configurations due to its adding and abstracting ability. Thanks to modularity, the flexibility is an easy step and the bridge is able to bridge every gap. The interchangeable components can be kept in storage and adapted to the specific site after the disaster immediately.
The second term, is deployability. In order to achieve the desired objective of a compacted form during transportation the structure will follow the rules of Deployability. It will consist of movable elements, which has to be really compacted in folded state for easy transport and durable and large, when being unfolded for assembly and use. The bridge will be both transportable and transformable. Transportable because of its ability to relocated and transformable because can change shape. In general, transformability is needed to make its transportability easier. Deployability concerns not only the pre-manufacture of the elements but also the pre-assembly of the entire structure in a factory and the unfurling or deploying it on site.
The last term is the materiality. The bridge has to be apparently stable, durable and long lasting, both in term of materiality and construction like the conventional bridges. It has to be lightweight for easy transportation and installation. The proposal is that the modules are made of FRP to reduce the weight and to facilitate transport and construction.

2.3 Design Strategy



3. MODULARITY

3.1 Definition

3.2 Standard Components

3.3 Modularity in Architecture

3.4 Advantages and Disadvantages

3.1 Definition

3.1 Definition

Modularisation = decomposition of a product into building blocks (modules) with specified interfaces. [Ulrich and Eppinger, 2004]

We live in a dynamic economic and commercial word surrounded by objects of remarkable complexity, sophistication and power. [Baldwin and Clark, 2000] Leading companies are meeting these challenges with a renewed focus on modularity. Modularity is a concept that has proved useful in a large number of fields that deal with complex systems. The fields range from brain science and psychology, to robotic, psychology, neuroscience, artificial intelligent and industrial engineering.
In everyday language, the word modularity is used almost as a synonym for the concept of "composed of parts". In broadest terms, modularization is an approach for organizing complex products efficiently, by decomposing complex tasks into simpler portions so they can be managed independently and yet operates together as a whole. [Mikkola, 2003] Hence, modular refers to the ability to assemble a larger system on-orbit from a number of individual intelligent units. Modularity is based on the idea of interdependence within and independence across modules. [Baldwin and Clark, 2000] Components used in a modular product must have features that enable them to be coupled together to form the complex form. Modular systems are built from highly independent ("loosely coupled") units/components, which are called modules. [Kamrani and Salhieh, 2002] The

Figure 3.1: LEGO: Modular Toy Manufacture
TYPE: modular combinations- clicking components
FUNCTION: toy
MATERIAL: acrylonitrile butadiene styrene,
Lego is a popular line of construction toys manufactured by The Lego Group, a privately held company based in Billund, Denmark. The company's flagship product, Lego, consists of colourful interlocking plastic bricks and an accompanying array of gears, mini-figures and various other parts. Lego bricks can be assembled and connected in many ways, to construct such objects as vehicles, buildings, and even working robots. Anything constructed can then be taken apart again, and the pieces used to make other objects.
Six pieces of 2x4 bricks can be combined in 915,103,765 ways.
Denmark, 1950
source: http://www.lego.com/nl-nl/
http://en.wikipedia.org/wiki/Lego]

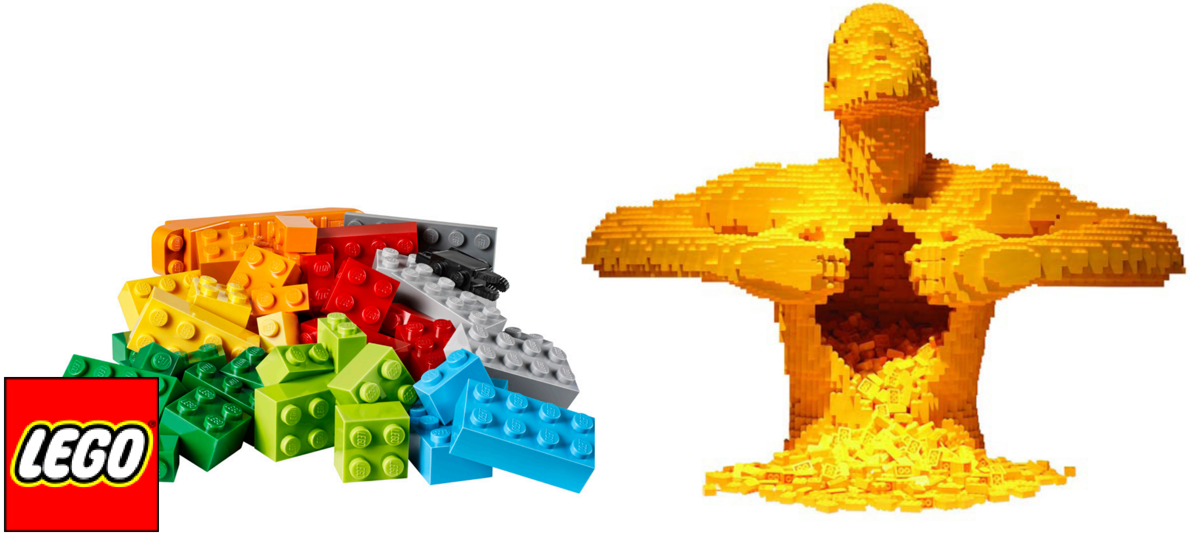


Figure 3.1: LEGO: modular toy manufacture

interactions between them are few and well defined by specific design rules. Through standardization of interfaces, modularization permits components to be produced separately and used interchangeably without compromising system integrity. Interchangeability and combinations requires that the modules have standardized interfaces and interactions. [Miller, 1998]
Current architecture industry, also the bridge construction industry, is based on all-in-one communications management unit (integral design). Such systems lack flexibility but they are associated with efficiency and control, easier and faster designing. If a firm adopts integral product architecture, it is required to adopt a unit of a completely specific ''ideal'' input to produce a final good.
On the other hand, modular approach provides a flexible, cost-effective and fully deployable and adaptable design. In this case, components are designed to interact with one another through standardized and codified interfaces. [Van Assche, 2006] Modularity can lead to greater product variety, shorter time-to-market, and lower production costs.
Two dominant approaches have emerged that characterize the module's independence from other modules as either functional or structural. The "functional approach" refers to a module as a system's component that is functionally independent from other components within the same system. According to [Urlich and Eppinger, 2004]: "A modular architecture includes a one-to-one mapping from functional elements in the function structure to the physical components of the product, and specifies de-coupled interfaces between components." In contrast, the "structural approach" bases

the definition of module on purely structural elements, so that a module is made up of components that are tightly connected among themselves and loosely connected with the components of other modules. [Miraglia, 2014] Our definition of modularity is based on relationships among structures, not functions.

3.2 Standard Components

3.2 Standard Components

A modular architecture may allow the use of a standard component. Component standardization is the use of the same component or module in multiple products or in the same product and is closely linked to product variety. Such standardization allows the firm to manufacture the chunk in higher volumes. [Urlich and Eppinger, 2004] Under most circumstances a standard component is less expensive than a component designed and built for use in only one product. Standard components, in general, exhibit higher performance (for a given cost) than unique designs. The use of standard components can lower the complexity, cost and lead time of product development. [13]

3.3 Modularity in Architecture

3.3 Modularity in Architecture

Over the past century, these processes have developed a stigma of "cheapness" and "poor quality." However, through modern technology, that image has changed. Now it's a key component of the drive to improve construction industry productivity. Historically, the main use of modular construction was in portable or temporary buildings, but this prefabricated construction technology using volumetric units is now used in a wide range of building types, from schools, hospitals, offices, and supermarkets to high-rise residential buildings. Although modular units have been used for many years in portable buildings, designs using load-bearing modules only date from the early 1990s.
Modular construction provides a new way of building based on factory-made (off-site) units, under controlled plant conditions, that are transported and installed on site to create the complete structures. These applications highlight the key benefits of rapid and high-quality construction, and economy of scale in manufacture.

3.4 Advantages and Disadvantages

3.4 Advantages and Disadvantages

The purpose of a modularization may be to obtain advantages in design, production and installation. The benefits of modular off-site construction may be focused on certain market sectors, where there is a demand for speed and safe of construction, flexibility, simplicity and economy in manufacture.
1. Speed: Time is significantly the bid-win for modular offsite structures, because of its ability to achieve a rapid, reliable construction program by reduced exposure to risks, such as adverse weather conditions, increasing productivity in factory production and reducing requirement for on-site

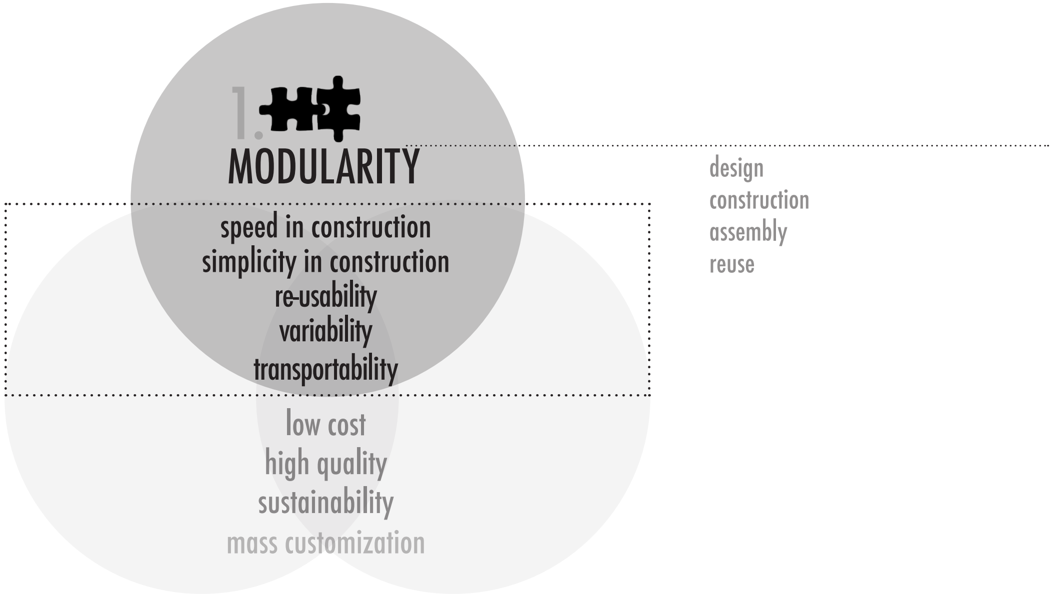


Figure 3.2: The advantages of Modularity related to the instant connection bridge

labor.

2. Simplicity: Modularity is a simple but powerful concept. Modularity= Simplify Complexity + Amplify Variety. Hence, it raises the possibility of complex structures using very few different elements. [Escrig and Brebbia , 1996]

3. Flexibility: The modular structures give the ability to dismantle the structure and reused elsewhere providing multiplies options inherent in a design. [Baldwin and Clark, 2000] In addition components can be replaced, changed and improved over time without redoing the whole. Portability implies that it can be broken down into pieces (or modules) small enough to be carried to the work place by a human operator and quickly assembled. Each module would have to be carefully designed to be lightweight and durable. Such a weight restriction creates an unusual demand to use special lightweight materials (composites or carbon fiber). [Kamrani and Salhieh, 2002]

4. Cost: The primary economic benefit is the speed of the construction process. Shorter build times leading to reduce site management costs. Initial element cost may be more expensive but savings from offsite benefits should be considered (reduce: risk, abortive work and defects, prelims and site overheads, production time, better quality so reduced maintenance).

5. Quality: Higher quality achieved by the factory-based construction process and predelivery checks. The independent components can be produced and tested separately before they are integrated into a modular product. [Kamrani and Salhieh, 2002]

6. Sustainability: The off-site manufacturing process in modular construction achieves many sustainability benefits that arise from the more efficient manufacturing and construction processes, the improved in-service performance of the completed building, and also the potential reuse at the end of the building's life. Materials use and waste are reduced because off-site manufacturing processes lead to more efficient bulk ordering of materials in the correct sizes for the particular project, and to less site damage. Simultaneously, there are greater opportunities for recycling in factory production.
7. Mass customization: Firstly, the focus on customer needs leads to customized products, which means companies have to manage a greater variety of products. Secondly, competition enforces companies to strive for efficiency in the business chain: to reduce costs, increase quality and reduce response time. Modularization is often mentioned as a means for handling these seemingly conflicting demands - and frequently in connection with the manufacturing concept of mass customization. The idea is that a broad variety of products can be produced by combining a limited number of modules. In this way modularity balances standardization and rationalization with customization and flexibility. [Miller, 1998] This is despite the fact that for many years it was a common thought that companies had to choose a strategy as either mass producing- standarazation (The mass production is a production of a large number of identical or very similar components to realize the benefits on economies of scale.) at the expense of customization at the expense of efficiency. Modularization can ideally lead to satisfy particular customers requirements while still maintaining the efficiency and low development cost of mass production. [24]

Essentially, in modular and other off-site construction methods, slow unproductive site activities are replaced by more efficient and faster factory processes. However, there are serious obstacles to the increased use of these solutions, which are associated with the ability of the design and construction community to respond to the opportunity and new ways of working:
1. Lack of knowledge among the design community of the solutions that are available and uncertainty as to how to integrate modular manufactured solution into an otherwise traditional construction process. The tendency of the part of some members of the clients professional team to regard the use of offsite solutions as something novel, unknown and therefore inherently risky and best avoided.
2. It turns out that modular systems are much harder to design than comparable interconnected systems because at the end all the independent components have to function together as a whole.

4. DEPLOYABILITY

3.1 Definition

3.2 Advantages

3.3 Design Principles

3.4 Deployable Systems and Types

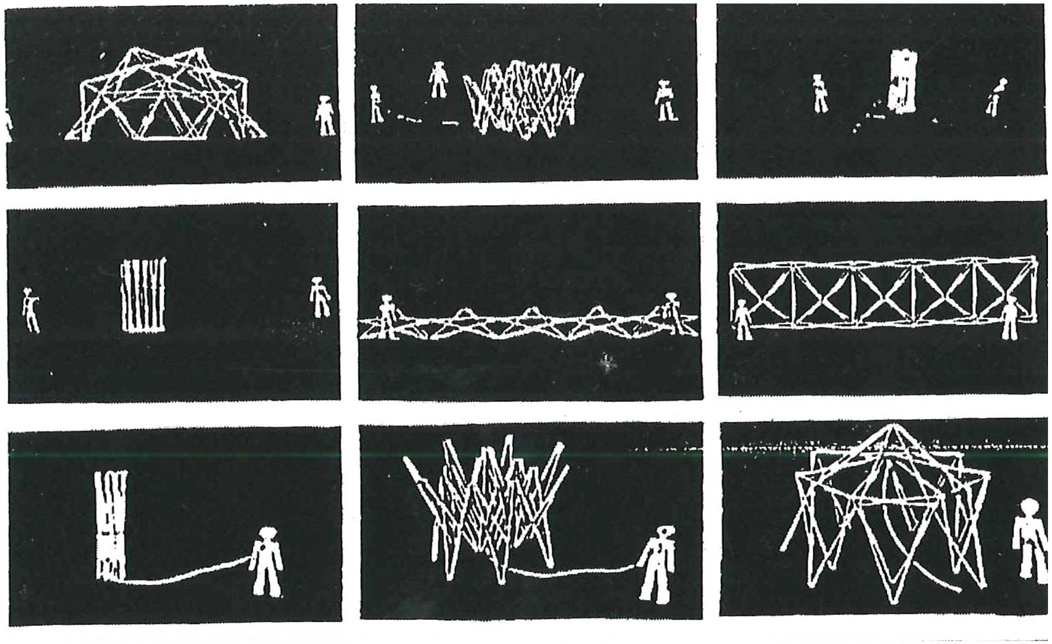


Figure 4.1: Some examples of deployab;e structures. [source: Gantes, 2001]

4.1 Definition

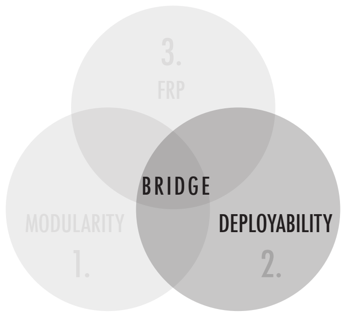
4.1 Definition

"*Deployable Structures is a generic name for a broad category of prefabricated structures that can be transformed from a close compacted configuration to a predetermined, expanded form, in which they are stable and can carry loads*" [Gantes, 2001]

Normally, when we apply pressure to an object, it may respond by bending, breaking, squashing or resisting inertly; however, many other responses are also possible. Specific controlled behaviors such as expansion, dilation, folding, and shape change can be designed into an object adding to it the term deployability. The word deployablity refers to an object or structure that has an innate property of controlled change.

Deployable structures are typically understood as temporary transportable structures that can be reused and relocated with relative ease erected and dismantled quickly reducing working time at the site. Apart from the concept of deployable structures, the concept of transformable structures is proposed. Transformable structures possess the main characteristics of the deployable structure while having the flexibility to achieve different transformed configurations. Due to this inherent transformability, deployable structures can be considered a special case within the boarder class of adaptive structures. [Gantes, 2001]

By definition, a structure is an assembly of materials intended to sustain loads, whereas a mech-



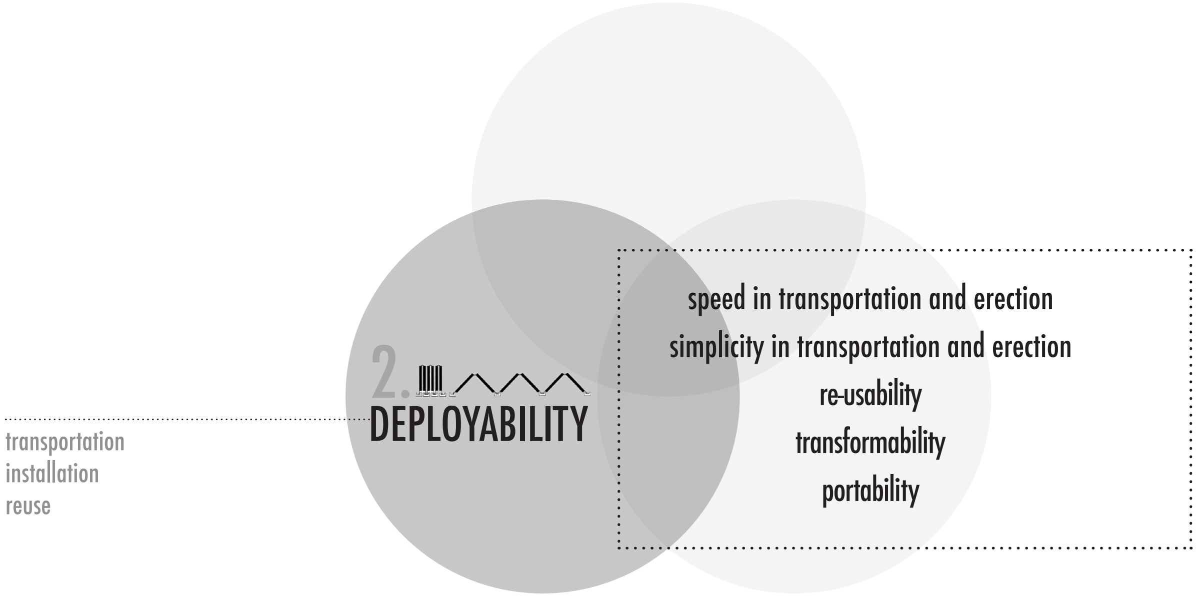


Figure 4.2: The advantages of Deployability related to the instant connection bridge

anism is an assembly intended to convert force into controlled movement. A deployable object is a hybrid between a structure and a mechanism. It is defined as a mechanism because it converts applied force into movement. However, normally mechanisms are not seen as integral objects and the emphasis during the design is on producing trajectories to achieve a particular function. Thus it is structure and mechanism at the same time: the links of the mechanism (transferring motion) are identical with the structural elements (providing support and shelter). It can be solid at times, flexible at others. The codes that govern moving structures and elements derive from rules and regulations from the realm of mechanical engineering and follow a somewhat different arrangement to the building regulations with regard to planning and execution. This is due to the fact that, unlike architectural elements, in mechanical engineering are generally serially produces and do not have any specific relationship place. [Schumacher et al, 2010]
Several kinds of deployable structures exist, including masts, slabs, grids and space frames for both earth-based and space applications. The erection is then operated by simply articulating the various components of the structure, resulting in a fast erection process.
Deployable structures are type of structures that consists of elements linked together in the factory, satisfying a pre-assembly geometry configuration and packaged in a compact configuration, thus very rapidly deploying large-span and volumes and complete structures. [Gantes, 2001]
The flow of a deployable structure could be described as following: Initially, the structure is trans-

ported in a compacted bundle configuration at the site. There, the force that is applied to the object in transformed in motion, which deploy it. Ones the structure expands, it is locked and it "freezes".

4.2 Advantages

4.2 Advantages

Architects and engineers demonstrated a growing interest in studying and experimenting with these mechanisms since they offer important advantages over other systems because of the relative simplicity of their stress-free assemblies.
There are numerous practical reasons to make a deployable object:
1. Speed and Simplicity: Easy and rapid erection, since the object is pre-assembled there is no need for special skill requirements for erection. Simultaneously, their erection result from simply unfolding its compact. Transportable building can take days, hour or minutes to erect and they are often referred to installations after a disaster.
2. Reusability: Simple to dismantle for reuse and reusability, since strike and re-deployment are easy, fast and inexpensive. There is a contemporary perception that portable buildings are low-quality tools, cheap and disposable. However, temporary in sitting does not necessarily mean temporary in existence and it characterize it ability to move in order to reuse or recycle.
3. Transportability: easy to pack and transport. Transportable architecture should be envisages as ephemeral; one day it is there and the other it is gone.
4. Transformability: Compacted packaging for shipping and storage due to the compact shape in the undeployed form.
5. Cost: The cost is competitive compared to other alternatives. The Deployability conditions implies an extra cost over that of conventional, non-deployable structures due to the need to employ a much more sophisticated design and the use of more versatile and expensive connections and mechanisms. However, this can be balanced by the advantages that the structure offers.
The restrictions imposed by the need for complex design and detailing, which are necessary to achieve deployability. Design for transformation with associated disassembly depends on decisions made within design domains of deconstruction. However, the above advantages outweigh the disadvantages.

4.3 Design Principles

4.3 Design Principles

The goal for the designers should be to design the members for regular loads and to obtain the deployable features as "bonus"- "add-on" without adding weight to the structure or decreasing it load-bearing capacity.
The design of such transforming objects is based on several key principles.
Modularity: A deployable object is made of many parts that act as an integral whole, following the

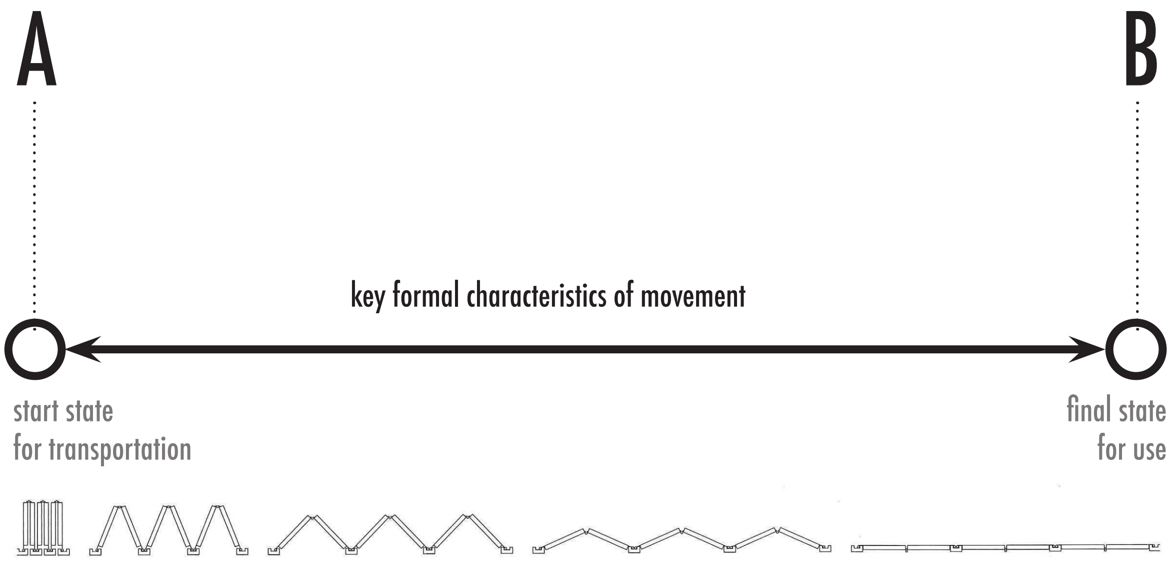


Figure 4.3: The different phases during the deployable process

modular concept as we analyze before and it is made up of linkages- interfaces having unique properties. Most of them are based on its underlying geometry.
Stability: The primary issue in deployable structures is the stability, especially when there is a load bearing structures like a bridge. When it is fully unfolded, the structure should transmit the idea of strength and give an impression of security, resembling a final product instead of an assembly in a stage of deployment.
Flexibility: Due to their transformable form, they characterize as adaptable structures.
Materiality: lightweight
According to the modular design and building deconstruction, the elements of a deployable object have to be independence, and exchangeability. A structure can be transformed if its elements are defined as independent parts, and if their interfaces are designed for exchangeability. The connections between the independence components are the exchangeable elements of the object and contribute to the increased disassembly and transformation potential of structures. As a result, during the design process of a deployable structure, emphasis must be given in both components (geometry, material) and their connections.

4.4 System and Types

4.4 Systems and Types

For some movable structures, the movement can be in one, two or three dimensions, according to

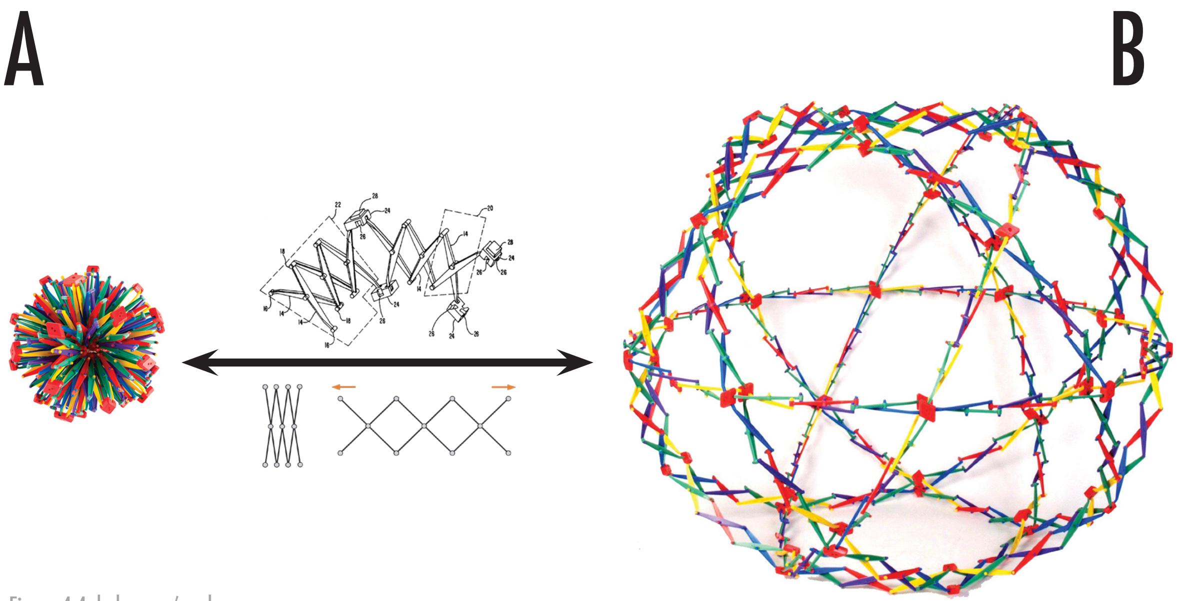


Figure 4.4: hoberman's sphere

the mechanism.

As, it mentions above, the design becomes a mixture of architecture, industrial design and engineering.

Applications for deployable structures may be found in recreation and exhibition structures, the aerospace industry, in the military field situation, construction site facilities, as well as in emergency situations as shelters. [Gantes, 2001] The current graduation aims to the application of this technique creating an emergency bridge.

The types of structural member could be [Gantes, 2001]:

1. Struts: where the basic modules are stiff 1D bars
2. Surfaces: which are 2d elements
3. prestress (membrane) or pneumatic structures: consisting of flexible 1d cables and/or 2d membranes
4. tensegrity structures: consisting of combination of stiff rods and flexible cables

Our focus is on pantograph structures (sophisticated hinged systems, which use scissor mechanisms or pantographs to create the final product), which they will be explained will in next chapter.

Figure 4.3: hoberman's sphere
the world of magical transformation
TYPE: transformable design
FUNCTION: toy
MATERIAL: plastic
The transforming sphere

A Hoberman sphere is an isokinetic structure patented by Chuck Hoberman that resembles a geodesic dome, but is capable of folding down to a fraction of its normal size by the scissor-like action of its joints, as it will be explained in next chapter. Several toy sizes exist, with the original design capable of expanding from 15 centimeters (5.9 in) in diameter to 76 centimeters (30 in).

A Hoberman sphere typically consists of six great circles corresponding to the edges of an icosidodecahedron. At the connections there is an extra component, a connector (in total there are 50 connectors10 in each circle).

The Hoberman sphere can be unfolded by allowing certain members to spread apart. The operation of each joint is linked to all the others in a manner conceptually similar to the extension arm on a wall-mounted shaving mirror.

Hoberman Sphere manifests the designer's idea of "making structures that transform their size and shape". The pieces of the sphere are interlocked and able to spread apart allowing the structure to contract and expand to a much larger form of its normal size while keeping its shape. Double-armed joints allow scissor-like actions, which maintain the included angle of the edge throughout the transformation.

New York, 1995

[sources:http://www.hoberman.com/fold/main/index.htm# and http://transformabledesign.com/project/a-5-1-hoberman-sphere/]

The angulated elements, consisting of a pair of identical angulated rods connected together by a scissor hinge. In analogy with elements made from straight rods, which -under certain conditions- fold while remaining the end pivot in parallel lines, angulated elements subtend a constant angle as their rod rotate. This property is exploited in Hoberman's foldable structure and in Servadio's foldable polyhedral. [Escrig and Brebbia , 1996]

5.MATERIALITY

5.1 FRP

5.2 Advantages and Disadvantages

Figure 5.1: Specific Young's moduli of common structural materials
In emergency bridges where weight is critical, specific strength and stiffness become important parameters in material selection
[source: Escrig and Brebbia, 2000]

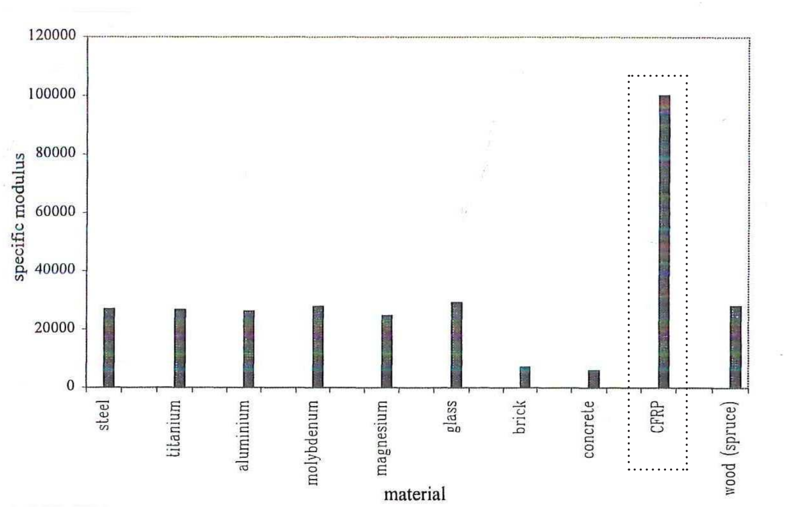


Figure 5.1: Specific Young's moduli of common structural materials

5.1 FRP

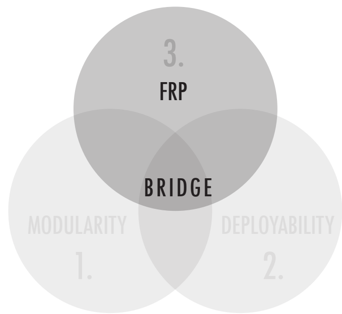
5.1 FRP

In an ideal structural design, the function, form and materiality have to be seamlessly interwoven. The selection of the suitable material has proved critical to efficient bridge construction, especially when there are extra requirements such as emergency, modularity and deployability. All of the three former characteristics require a material, which it will be durable with high capacity but mainly lightweight.

Fiber-reinforced polymer (FRP) materials are notably attractive for structural applications in aerospace, marine and automobile industries due to their excellent engineering properties, such as high strength, good corrosion resistance and low self-weight (low density).

FRP bridge technology has moved rapidly from laboratory prototypes to actual demonstration projects in the field to replacement decks, strengthen existing structures and construct new bridges. Among these applications, the construction of bridge decks, pedestrian bridges, and light-traffic vehicular bridges have been increasingly promoted in recent years. Heavily loaded vehicular bridges have also been constructed out of FRP more recently. [Zhang et al, 2014]

Regarding an emergency bridge, where weight is critical for the transportation, and simultaneously strength and stiffness become important parameters, the material selection is crucial. To minimize weight we must maximize material efficiency and hence specific properties. This limitation explains why new materials, such as FRP (or CFRP), are actively being researched and are more desired, despite their cost. [Escrig and Brebbia , 2000]



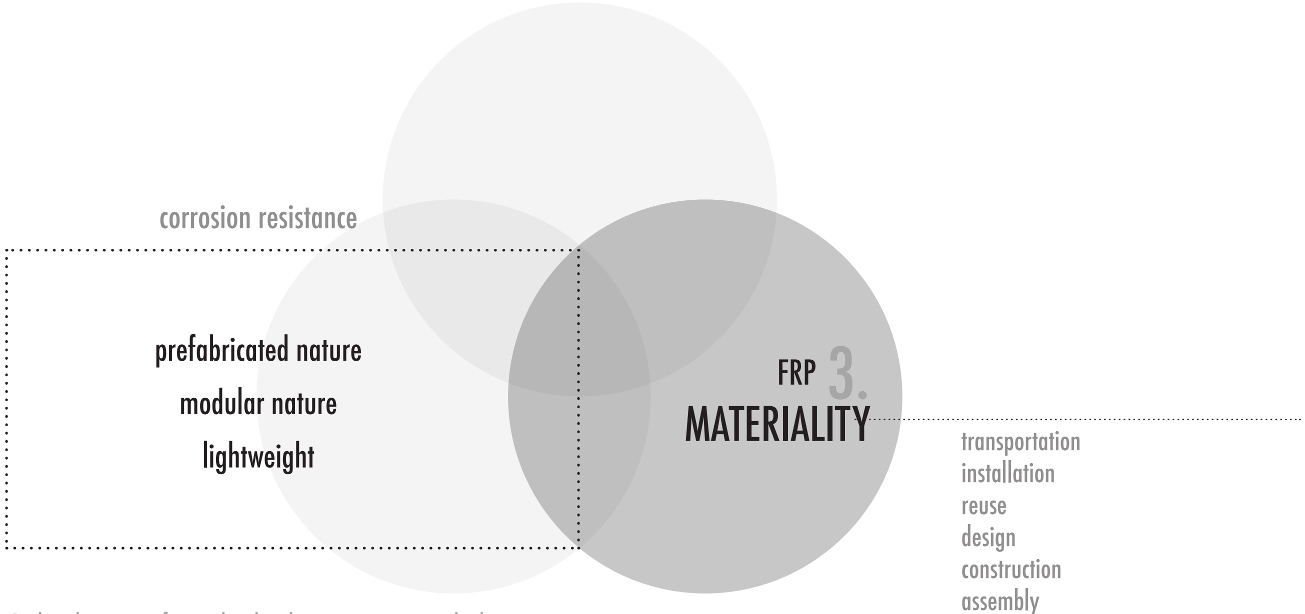


Figure 5.2: The advantages of FRP related to the instant connection bridge

5.2 Advantages and Disadvantages

5.2 Advantages and disadvantages

Analytically, some benefits of the material that are relevant to our design are:

1. Prefabricated nature of FRP for complex shapes. It has the ability to speed construction and improvement in quality due to the environmentally controlled factory. [O'Connor and Hooks]

2. Modular nature of FRP. Additionally, because of the short time needed to fabricate a bridge and the possibility of stockpiling standard sizes, a project's initiation and planning phase can be dramatically decreased. This can be a big benefit in emergency situations. [O'Connor and Hooks]

3. Light-weight nature of FRP. A lightweight FRP structure can easily transported, assembled and installed to the site in comparison with steel or concrete parts of construction. As a result time and effort are reduced during the transportation. (FRP footbridges are lightweight, for example 2 tones for a 12 meter span).

4. Corrosion resistance- long service life. In comparison by other materials, it lasts longer, while requiring minimal maintenance and the same structure can be used again and again. For example, steel reinforcement and structural steel members are known to be susceptible to corrosion, while concrete could also crack and spall due to sulfate attack, freeze thaw and other detrimental processes. FRP bridges are designed with a 120 year design life and will not corrode.

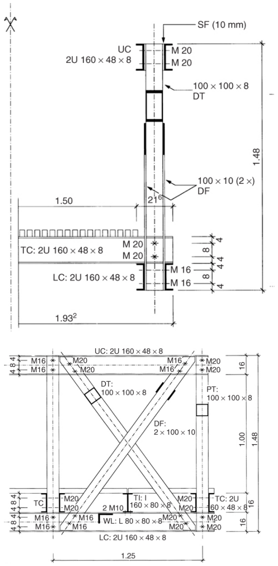


Figure 5.2: Fibre-reinforced plastic temporary footbridge, Pontresina, River Flaz, Zurich
It has bolted connections at one span and glued connections at the adjacent span. Temporary lightweight pedestrian bridge, installed each year in the Autumn and removed in the Spring. From these constraints, a two-span bridge of 2 m × 12.50 m resulted with 1.48 m deep truss girders on the lateral sides of the walkway.
[Baus & Schaich, 2008]

Figure 5.3: Fibre-reinforced plastic temporary footbridge

However, there are certain disadvantages associated with using FRP at the present time, which must be taken into account during the design process. [O'Connor and Hooks]

1. Cost. Initial cost is probably the largest barrier to widespread use of these materials. Even when there is a valid case for their use, it is not always obvious that FRP provides a cheaper alternative.
2. Elasticity. FRP has a low modulus of elasticity when compared to steel and concrete, which leads to large deflections of the structure. This has a direct affect on the stiffness of an FRP structure. In order to meet serviceability requirements for deflection, FRP systems are inevitably over designed from a strength perspective. New shapes, manufacturing methods, and hybridization with other materials may lead to a more optimal design, but for now we accept a high factor of safety that is counter to economy of cost.
3. Uncertainty:. Similarly, uncertainty over material properties gives rise to conservatism and subsequently higher cost. Until manufacturing methods become adopted that assure consistency in material properties that are verifiable with standard testing methods, specification writers will necessarily need to write a tight specification to insure the finished product will be safe and reliable. Moreover, most bridge designers are not experts in composite materials and prefer to stay with well understood materials rather than venture into the world of new materials and fiber architecture.
4. Low fire resistance.

6. DESIGN

under consideration

6.1 Preliminary Design

6.2 Final Design

6.3 Detailing

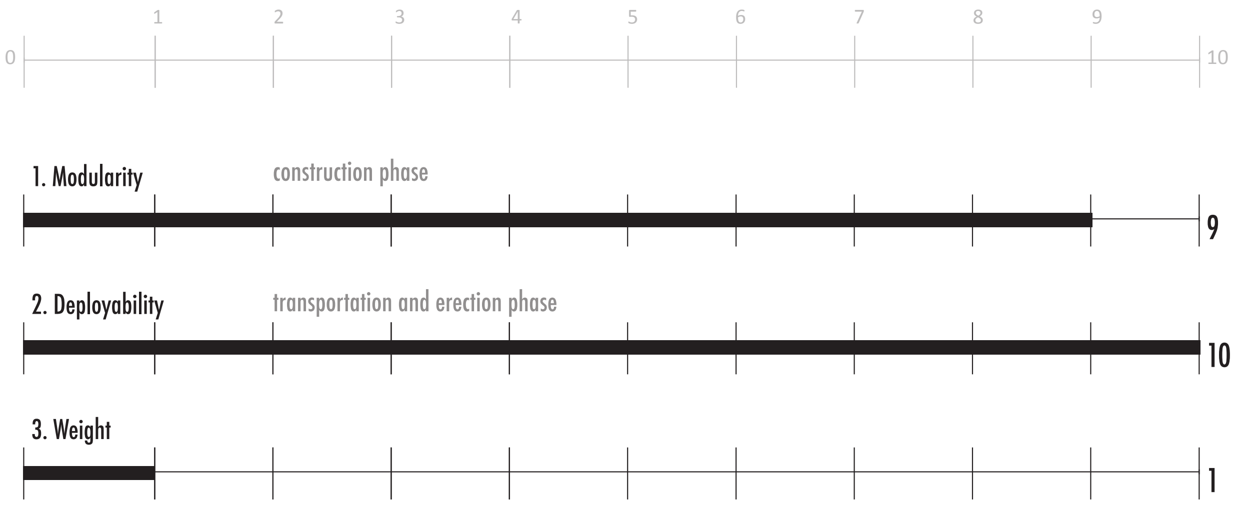
6.3.1 Superstructure

6.3.1 Substructure and Connections

6.3.2 Deck

6.3 Drawing of Final Design

6.4 Erection Process



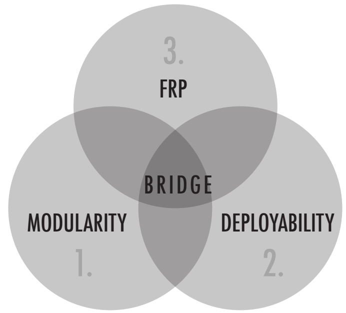


Figure 6.1: The three important features of the design

6.1.1 Summary

6.1.1 Summary

The graduation topic, considering the existing applications of emergency bridges, as well as the requirements that are mentioned above, propose a lightweight- FRP, modular, deployable bridge for emergency that have been used all over the world to reconnect communities, restore vital lifelines and support disaster relief. The instant connection will be designed as a modular single-traffic-lane bridge with a span length that varies form 4-20m according the units number that are assembled. The modular, transportable 'out-of-the-box' nature of the product combine with the use of interchangeable standard components means almost any length of bridge can be installed easily and quickly. It employs modules formed by prefabricated elements, creating a system with lightness, mobility, rapidly of assembly and erection simplicity.

6.1.2 Preliminary Ideas

6.1.2 Preliminary Ideas

There are different concepts of deployable structures but all of them are based on a similar concept. Our focus is on deployable structure made of struts- bars (straight or angular) or plates. . In this point of view two concepts are presented.

CONCEPT 1: pantographic bridge

The basic unit is a scissor-like element. The term 'scissor' was adopted fairly recently to describe this mechanism, due to its similarities with the cutting device. It is formed from two rigid bars, with hinges at the ends and to their intermediate points by a shear resisting element with pivotal connection, which allow their relevant rotation. A scissor hinge is a revolute joint whose axis is perpen-

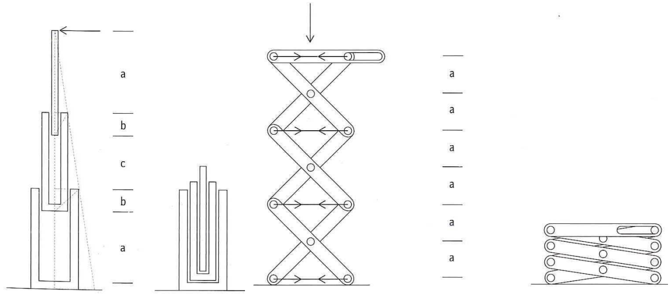


Figure 6.2: Telescopic shaft and Scissor lift[source: Schumacher et al, 2010]

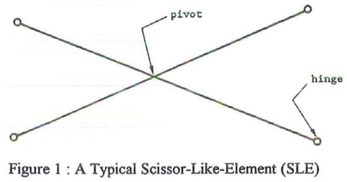


Figure 6.3: A typical scissor like element [source: Escrig and Brebbia , 1996]

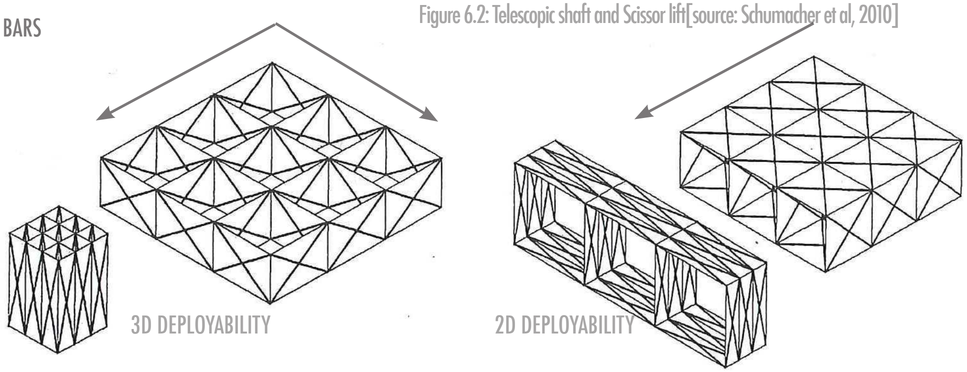


Figure 6.4: Pantographic slabs by Raskin in two and three dimensions [source: Gantes, 2000]

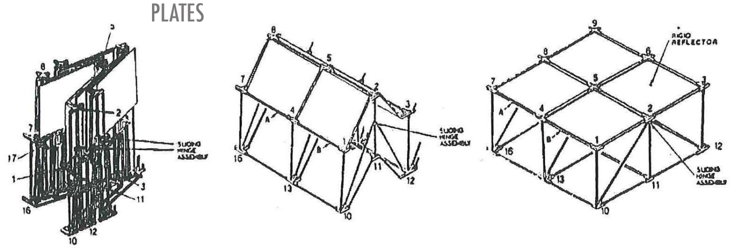


Figure 6.5: Deployable structures with flat reflectors [source: Gantes, 2000]

dicular to the plane of the structure. During folding, each set of collinear pivots remains collinear, and all pivots became coincident. In theory, this is resulting to a fully folded configuration. When several units are placed among a straight line, form a planar pantographic beam. [Escrig and Brebbia , 1996] This beam can be doubled (or even repeat in the vertical direction) creating the truss beam and a two or three-dimensional foldable bridge. The fundamental elements in this structure are the members them selves. Another important feature are the joints, which they have to permit the structural members to turn within their plane to an axis perpendicular to the axis of turning. The node-connection is the must complex element since requires connection in different directions. The third important feature is the element used to lend the deployable structure to rigidity and convert it from mechanism to a structure. These members could be rigid bars, flexible cables or both. [Escrig and Brebbia , 1996]

The shape of the scissor components, their scale, modularity, frequency and material are crucial variables that can be manipulated in different ways to define the transformable or transportable nature of the structure.

There is also the possibility to combine the scissor principle with telescopic elements, while stabilizing the structural system, using a truss-like geometry. Telescopic system: is a cantilevered structure that can sustain bending moments with the widest diameter at its point of fixation. However, there is a limitation to the dimensions, because the individual telescopic elements have to be able to insert into one other. Hence, the system is not modular. [Schumacher et al, 2010]

CONCEPT 2: rigid flat surfaces- accordion- like bridge

The accordion-like movement permitting the whole structure to fold in one direction.

When one works with transformable structure using bars and the resulting structure is a mesh, it is necessary to add a cover, usually a membrane because is light and foldable, to complete the surface. However, in case of a bridge, a more stable and durable deck is needed. Hence the idea to incorporate rigid sheet in the modular deployable structure, which can function as deck can be a design option. [Escrig and Brebbia , 2000]

6.1.3 Considerations

6.1.3 First Considerations for the Connections and Erection Process

Stiffness: An deployable structure is by its proper nature a mechanism, in order to be able to fold, as a result the connecting points must be fixed converting it o a structure. The easiest method to achieve stiffness in a mechanism is the adopted solution, namely to add extra stiffeners after deployment to the whole structure. It consider a reasonable solution however, it needs a considerable effort of adjustment and extra time during erection. Another similar interesting solution and more desirable, it will be the using of stiffeners with a blockable central articulation (bolt?). [Escrig and Brebbia , 1996]

However, there are some examples that avoid that and must be examined aiming to a self-locking solution, which can be stable in the final deployed configuration, guarantee that their members are straight and stress free, except from dead load effect. An example for that is the incompatibility between the members lengths, which lead to the occurrence of strains and stresses resulting a snap-through phenomenon that “locks” the structure in their deployed configuration.

Erection: The erection is probably the most important part in emergency. The erection process can be a catalytic for many decisions, such as the material, the joints etc.

(One option for fast erection, it could be the use of springs)

Scissor structures of small to medium scale can be designed to operate manually or through a simple mechanical procedure. Those of larger scale demand a higher technological investment in the design of the structural components and the movement process to ensure their efficient operation.

Joints: The material of the joints should offer high levels of fatigue resistance and at the same time allow a smooth pivoting hinge avoiding excessive friction. To minimize joint loads and, therefore, element section sizes, cladding materials should also be as lightweight as possible.

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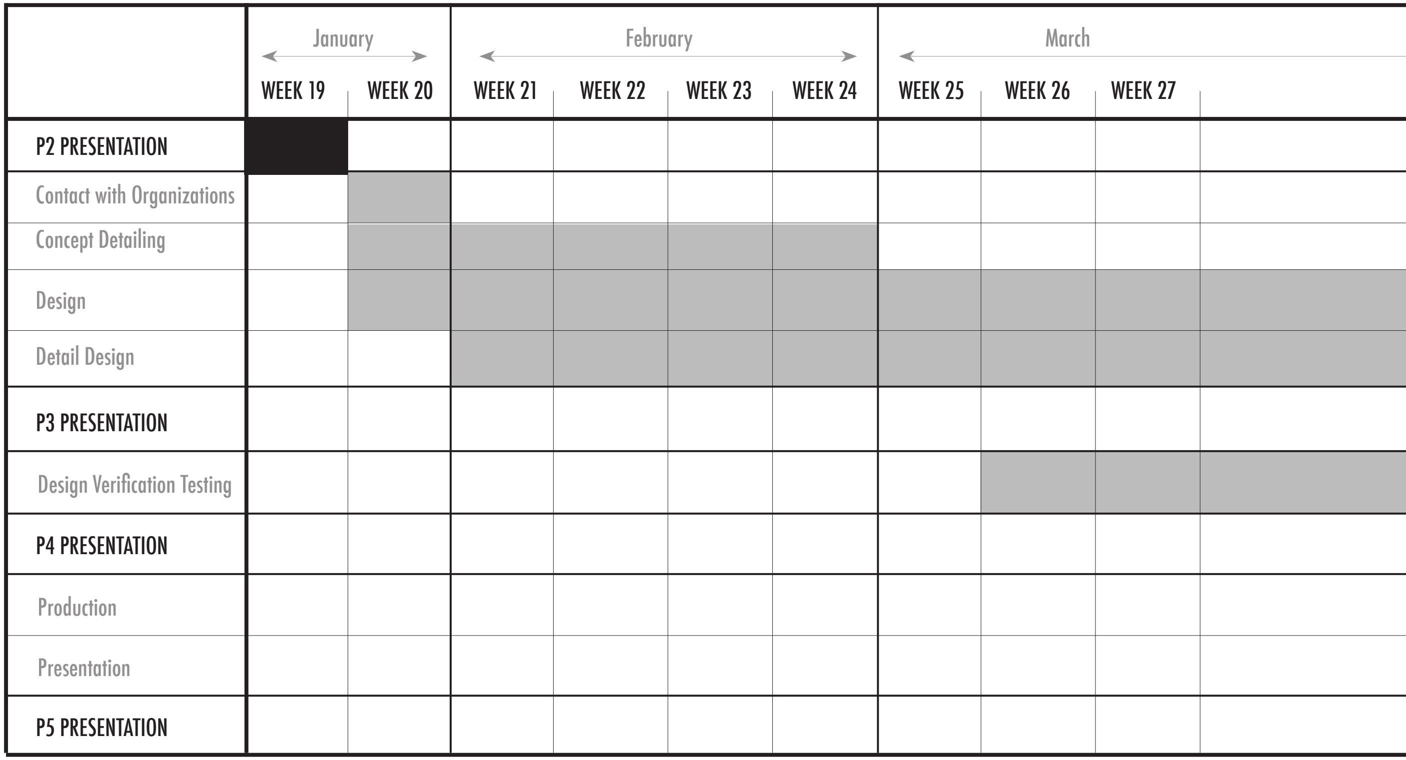
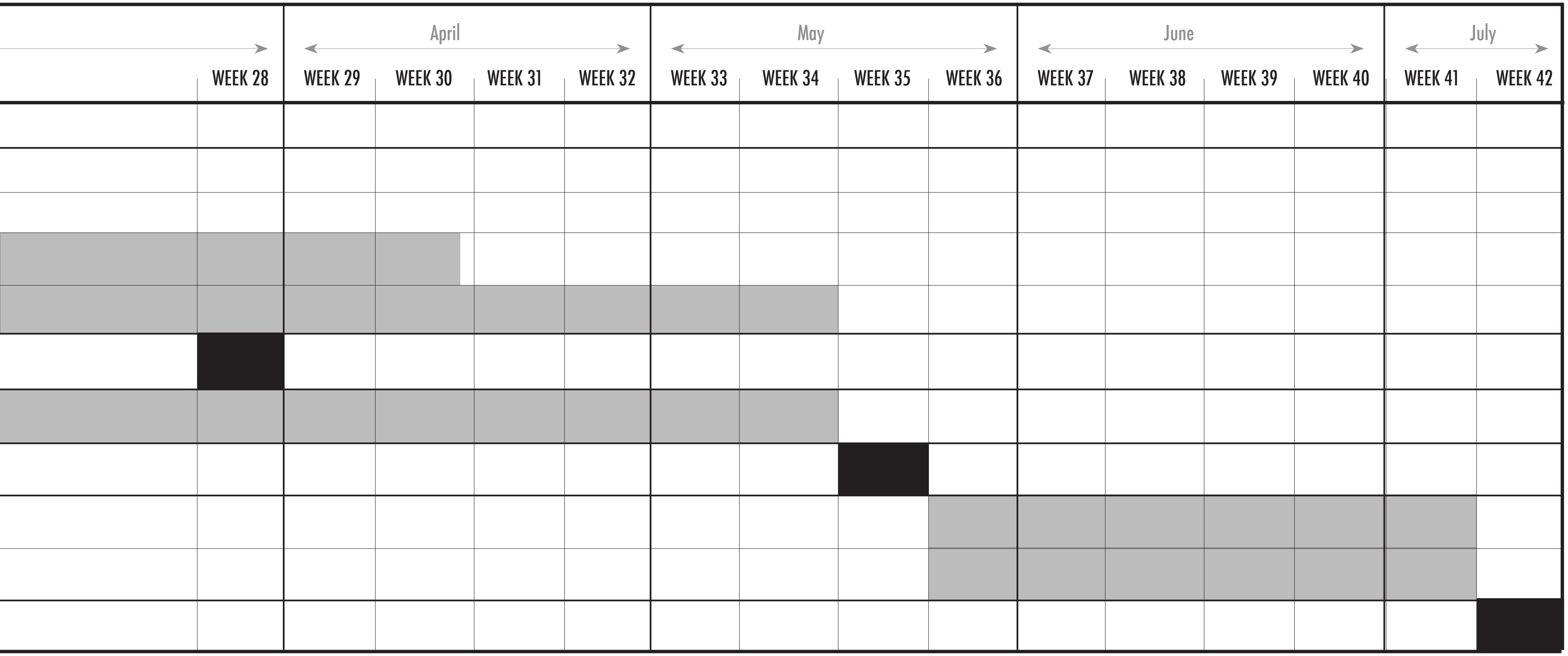
TIME PLANNING




April
May
June
July
WEEK 28
WEEK 29
WEEK 30
WEEK 31
WEEK 32
WEEK 33
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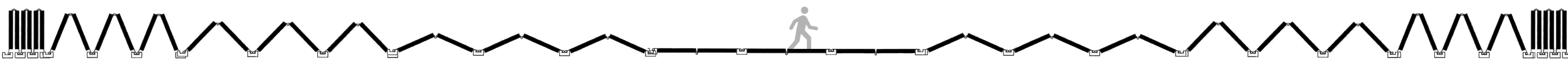
WEEK 35
WEEK 36
WEEK 37
WEEK 38
WEEK 39
WEEK 40
WEEK 41
WEEK 42



GRADUATION PLAN [P2]
TU DELFT
JANUARY, 2015