Precast Modular Construction of Schools in South Africa

by

Dean de Klerk

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Supervisor: Prof. J.A. Wium

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Declaration

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Synopsis

This thesis is a study in the use of precast modular construction as an alternative to current methods of school construction in South Africa.

Precast Modular Construction is a concept which utilises the principles of prefabrication and precast concrete. Concrete components, be they beams, columns, slabs or full volumetric modules, are manufactured either off-site in factories or in on-site facilities. These components are then assembled on-site to form the structural envelope of a building.

This approach contains many inherent advantages: Time is saved due to on-site and off-site work happening concurrently and hence earlier building occupancy results which directly translates to cost reparation; quality is improved due to most of the work being carried out in a controlled factory environment; and health and safety is heightened. However, when viewed from a South African perspective, the fact that less work is done on-site indirectly implicates job loss, a serious issue in the country.

Furthermore, implementing a prefabricated approach in the construction of South African schools requires a complete restructuring of the Department of Public Works' current procurement approach. Prefabrication requires maximum integration between all parties to a project so that design and constructability issues can be addressed at an early stage. The design-build contract strategy is found to be the most integrated approach and allows for optimal collaboration between all project members.

However, to only change the procurement route would not suffice as a complete solution. A broader approach is required which addresses issues prevalent in South Africa. These issues include job creation and the establishment of a sustainable and knowledgeable industry. Concepts such as standardisation and strategic partnering, in response, satisfy the need of the manufacturer - for economies of scale, and the employee - for creation of secure working environments.

Verification is obtained from all of the aforementioned to propose that the optimal solution to successfully implement Precast Modular Construction for schools in South Africa would

be to implement a design-build procurement approach, whereby a single design-build contractor is awarded by the Department of Public Works a contract, via competitive tendering, for the construction of a predetermined number of schools, preferably exceeding 3, over a given contract period using a standardised design and utilising customisable standardised prefabricated precast construction systems, i.e. Precast Modular Construction.

This proposal will theoretically result, amongst other things, in the following:

- Precast manufacturers will have a confirmed number of orders for products, and can hence be assured of a constant flow of income. This translates directly to an increase in both employment and job security at the manufacturing plant.
- The economies of scale principle is satisfied and prefabricated components can therefore be manufactured or 'mass customised' in the most feasible way possible.
- The design-build contractor will be guaranteed employment for a given period, once again providing job security for its employees, of which the number can also potentially increase.
- The design-build contractor carries with it experience and lessons learned from each successfully completed project on to the next, and so becomes more proficient, resulting in better, higher quality schools delivered in shorter periods and with increased efficiency.

It is recognised that the proposal is untested in practise but in a socio-economic situation such as South Africa, where large numbers of schools are required quickly, the above proposal makes sense.

To additionally develop this hypothesis, further research is required in the fields of design-build procurement and strategic partnering.

Sinopsis

Hierdie tesis is 'n studie in die gebruik van modulêre voorafvervaardigte beton konstruksie as 'n alternatief vir die huidige metodes van skool konstruksie in Suid-Afrika.

Modulêre voorafvervaardigte beton konstruksie bevat baie inherente voordele. Tyd word bespaar as gevolg van werk wat gelyktydig op en van die terrein af gebeur. Dus word die gebou vroeër betrek wat direk lei tot kostebesparings. Kwaliteit verbeter as gevolg van meeste van die werk wat in 'n beheerde fabriek omgewing uitgevoer word en as sulks lei tot beter gesondheid en veiligheid van werkers. Egter, vanuit 'n Suid-Afrikaanse perspektief impliseer die feit dat daar minder werk op die terrein gedoen word indirek werksverlies, 'n ernstige probleem in die land.

Die implementering van 'n voorafvervaardigde benadering tot die bou van skole in Suid-Afrika vereis verder 'n volledige herstrukturering van die huidige verskaffing model. Voorafvervaardiging vereis maksimum integrasie tussen alle partye sodat projek ontwerp en boubaarheid op 'n vroeë stadium aangespreek kan word. Die ontwerp-bou kontrak strategie is die mees geïntegreerde benadering en laat toe vir optimale samewerking tussen alle projek lede.

Om egter net die verskaffing roete te verander, sou nie voldoen as 'n enkele oplossing nie. 'n Breër benadering word vereis wat kwessies algemeen in Suid-Afrika aanspreek. Hierdie kwessies sluit in werkskepping en die vestiging van 'n volhoubare en kundige industrie. Konsepte soos standaardisering en strategiese vennootskap, as oplossings, voldoen aan die behoeftes van die vervaardiger - vir 'n ekonomieë van skaal, en die werknemer - vir die skepping van 'n versekerde werksomgewing.

Die voorafgaande bevestig dat die optimale oplossing vir suksesvolle implementering van Beton Modulêre Konstruksie vir skole in Suid-Afrika sou wees om 'n ontwerp-bou verskaffingsprosedure te volg. Hierdeur kan 'n kontrak aan 'n enkele ontwerp-bou kontrakteur deur die Departement van Openbare Werke toegeken word, deur middel van ‘n mededingende tender proses. Daar word voorgestel dat die projek, vir die konstruksie van 'n voorafbepaalde aantal skole behoort te wees, verkieslik meer as 3, oor 'n bepaalde

kontrak tydperk met behulp van 'n gestandaardiseerde ontwerp. Voorts word daar voorgestel om gebruik te maak van aanpasbare gestandaardiseerde voorafvervaardigde beton konstruksie stelsels, dws Beton Modulêre Konstruksie.

Hierdie voorstel sal teoreties, onder andere, die volgende gevolge hê:

- Beton vervaardigers sal 'n bevestigde aantal bestellings vir produkte hê, en kan dus verseker wees van 'n konstante vloei van inkomste. Dit lei direk tot 'n toename in indiensneming en werksekerheid by die fabriek.
- Die ekonomieë van skaal beginsel is bevredig en voorafvervaardigde komponente kan dus vervaardig word in die mees haalbare manier moontlik.
- Die ontwerp-bou kontrakteur is gewaarborg van indiensneming vir 'n gegewe tydperk, as sulks ook die verskaffing van werksekerheid vir sy werknemers, waarvan die aantal moontlik ook kan vermeerder.
- Die ontwerp-bou kontrakteur neem ondervinding en lesse wat geleer is uit elke suksesvolle voltooide projek saam na die volgende een, en raak dus meer bedrewe, wat lei tot beter, hoër gehalte skole gelewer in korter tydperke en met toenemende doeltreffendheid.

Die voorstel is egter ongetoets in die praktyk, maar in 'n sosio-ekonomiese situasie soos die van Suid-Afrika, waar 'n groot aantal skole vinnig benodig word, maak die bogenoemde voorstel sin.

Om hierdie hipotese te ontwikkel, is verdere navorsing nodig in die gebied van ontwerp-bou verskaffing en strategiese vennootskappe.

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Chapter 1

Introduction

1.1 Topic

This dissertation describes a study in the use of precast modular construction as an alternative to current methods of school construction in South Africa.

1.2 Hypothesis

Precast Modular Construction is a feasible and effective method for the delivery of school buildings in South Africa.

1.3 Background

Prefabrication, specifically in precast concrete, is a concept not new to the construction arena, both internationally and in South Africa. Many projects have been completed successfully using prefabrication claiming notable time, quality and in some cases cost improvements (Haas et al., 2000), (Jaillon & Poon, 2009). More recently, precast concrete products and methods have been used internationally in the construction of schools due to the time advantages it presents compared to traditional construction methods (Endicott, 2000), (Canadian Precast Concrete Institute, 2005).

School projects have features that are well-suited to prefabrication. Classrooms allow for use of modular room design, and these projects also benefit from faster construction schedules. However, South Africa has been slow to adopt this practice and to its own detriment, as this process allows for a quick and efficient way of addressing the shortage of quality learning environments in South Africa.

South Africa is witnessing increasing levels of investment in infrastructure driven by its commitment to economic and social development. All spheres of government and state owned enterprises are challenged to increase the pace and efficiency of construction delivery. This is demonstrated by the recently introduced Infrastructure Plan that is intended to transform the economic landscape of South Africa, create a significant numbers of new jobs, and strengthen the delivery of basic services to the people of South Africa (Presidential Infrastructure Coordinating Commision, 2012). The plan, first announced by President Jacob Zuma in his State of the Nation address in February 2012, lists 17 strategic integrated projects that cut across energy, transport and logistics infrastructure to schools, hospitals and nursing colleges. Of significance is Strategic Integrated Project 13:

- **Strategic Integrated Project 13:** National school building programme
    - A National school building program driven by uniformity in planning, procurement, contract management & provision of basic services.

In addition, the recent budget allocated to the Western Cape by the Members of the Executive Council is R770 million for educational infrastructure. The National Education Department has made available a further R750 million in terms of the "Accelerated Schools Infrastructure Delivery Initiative". Thus the total educational infrastructure expenditure for the 3 financial years 2012/13 to 2014/15 will exceed R3 billion (Carlisle, 2012).

It becomes apparent that there is a clear intention by South African authorities to address the education dilemma faced by the country. Prefabrication is potentially a sensible and logical avenue the Public Works departments can follow to aid in the success of the above initiatives. Current procurement processes, however, do not allow for an innovative integrated environment where prefabrication can be most fruitful (Willemse, 2011), (Lewis, 2012).

The above background motivated the author to perform a study in the procurement and implementation associated with Precast Modular Construction and how it pertains to South Africa.

1.4 Objectives and Aims

It is deemed necessary when implementing a new or innovative process, to first provide a clear understanding and definition of what exactly the process entails. Since the precast modular construction of schools can be considered ‘innovative’, the owner/client of such a project will therefore require a clear and coherent understanding of what exactly it is they are undertaking. This thesis, being about school construction, accepts the client to be the Department of Public Works, and as such aims to achieve the following:

- Define the term 'Precast Modular Construction'.
- Obtain an understanding of the concept of prefabrication and more specifically, precast concrete.
- Attain a broad overview of which precast components are available to the project team.
- Determine the implications of prefabrication on time, cost, quality, socio-economy, logistics, health and safety, and procurement strategy.
- Identify a procurement strategy best suited to prefabrication, but specifically prefabrication in school construction.
- Introduce the concepts of 'Standardisation' and 'Strategic Partnering' as background to the last objective.
- Offer an all-encompassing proposal/plan for successful implementation of a precast modular solution to school construction in South Africa.

1.5 Scope and Limitations

Prefabrication can in general be accomplished in any building material, but for the purposes of this dissertation the term 'prefabrication' is only associated with concrete products. The reason for this being that the use of precast concrete is not an entirely new concept in South Africa, with various established manufacturers around the country. In addition, concrete is a material which is perceived favourably amongst disadvantaged communities, which is coincidently where the majority of schools are required.

Hence, large civil projects and any civil precast elements are not considered, such as pipes, kerbs, bridges and bricks for low cost housing. Rather smaller commercial and residential building structures and precast structural elements therein are considered. In other words, the construction of an office building is not very different to that of a school building and therefore examples of precast concrete application in both situations are considered.

Furthermore, the focus of this study is on management techniques and methods of improving the utilisation of precast modular construction. It is not the purpose of this thesis to provide in depth technical information regarding precast construction although, together with design and construction issues mentioned throughout the document, technical aspects such as the type of design codes used are discussed briefly. Procurement strategies are also not discussed in excessive detail, as this is an area of research which can become tremendously broad. Rather clear overviews of the procurement strategies are given.

1.6 Research Methodology

The approach taken by this dissertation was driven by the notion that most new ideas, such as the one this dissertation proposes, are in nature all innovative. Innovative ideas are generally born as a remedy to a problem to which no current solution exists. It is thus the approach taken by the author that an empirical study, where questionnaires would have been sent out to various industry professionals, would not have been of much worth, because obtaining opinions on an innovative concept from an industry that is not knowledgeable in that field would not amount to useful information.

Rather, this thesis concerned itself with information contained in literature, most of which had been peer-reviewed. It was felt that if a clear understanding and consensus of the literature could be achieved, it would provide the support needed to formulate educated assumptions and proposals.

In summary, the following methods were used to obtain the information contained in this dissertation:

- An extensive literature review was performed of hardcover books, scientific journals, periodicals, and websites.
- References are made to statistical information available from South African authorities.
- References are made to case studies both local and international.
- Consultations were held with various industry professionals including the Chief Engineer from the Department of Transport and Public Works in the Western Cape; and the Chief Director of Physical Resources for the Western Cape Education Department.

1.7 Chapter Outlay

This study is structured following the logic depicted in **Figure 1.1** and the subsequent paragraphs.

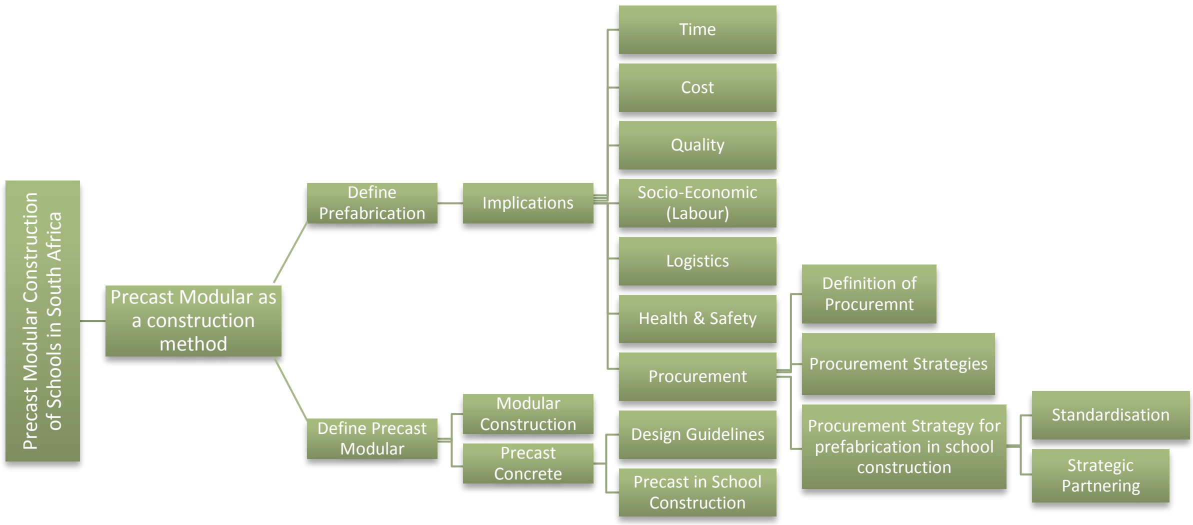

Figure 1.1 - Flow diagram depicting the breakdown of this research study.

1.7.1 Chapter 2 – Precast Modular as a Construction Method

This chapter introduces the concept of prefabrication. It then further dissects the term 'precast modular construction' into two parts, namely: precast concrete and modular construction. These concepts are discussed in more detail and applications of each are considered. The design codes and standards are discussed thereafter and specifically how they pertain to precast concrete design and construction. Also, implementation of precast concrete in the construction of schools is explored. Case studies of successful examples are showcased.

1.7.2 Chapter 3 – Implications of Using Precast Modular Construction

It is necessary when considering prefabrication to be aware of the implications on essential construction variables such as time, cost and quality compared to traditional in-situ construction. This chapter aims to show the implications of prefabrication (precast modular construction) on time, cost, quality, socio-economy, logistics, health and safety, and procurement, providing comparisons to traditional methods in some cases.

1.7.3 Chapter 4 – Procurement Systems

The purpose of this chapter is to elaborate on the topic of procurement as mentioned in **Chapter 3**. Various procurement strategies are evaluated, and then systematically a procurement strategy is identified that best suits the use of prefabrication in school construction.

1.7.5 Chapter 5 – Standardisation and Strategic Partnering

Standardisation and strategic partnership are introduced as supplementary to the findings of **Chapter 4**. These concepts are discussed in more detail, describing the advantages and applications of each in regards to this study.

1.7.6 Chapter 6 – Implementing Precast Modular Construction: A Discussion

This chapter uses all the information gathered in the previous four chapters and combines them in a logical manner in order to provide verification of the initial hypothesis, and in doing so create a proposal for implementing Precast Modular Construction. A discussion ensues in which the rationale behind the proposal is discussed and clarified.

Chapter 2

Precast Modular as a Construction Method

2.1 Introduction

Precast Modular construction, also sometimes referred to as 'Permanent Modular' construction, in its broadest sense is an extension of the ideas and principles associated with prefabrication, off-site fabrication, pre-assembly and modularisation. These are part of the broad spectrum of innovative 'alternative' building techniques available to clients, consultants and project managers seeking greater cost- and time-effectiveness in construction. It is therefore important to understand the concept of prefabrication/off-site fabrication before one can understand what is meant by the term 'Precast Modular'.

This chapter aims to introduce the concept of prefabrication so that when it is referred to later, there is a clear understanding of what the term entails. The main theme of this dissertation, however, remains the usage of precast modular construction but this is established to be akin to prefabrication. It is important to mention that although the term contains the phrase 'precast modular', it does not specifically refer to precast modular units, but instead to the parts that define it in respect of this study, namely: Precast Concrete and Modular Construction.

These two concepts are explored in more detail in this chapter and a simple overview is given of each. It is not the purpose or intent of this chapter, or dissertation, to identify a single precast solution for the construction of schools, but rather to merely provide an outline of what is available to the designer, contractor and client.

In addition, design codes and standards are discussed and specifically how they relate to precast concrete concepts and designs. Thereafter, applications of precast concrete in the construction of schools are examined with the intention of proving the initial hypothesis. All the same, a grasp of the concept of prefabrication (Precast Modular Construction) is first required and it follows hereafter.

2.2 Prefabrication

Throughout the research conducted for this study, the terms prefabrication, off-site construction, pre-assembly and modularisation were found to be used numerous times. Sources of literature refer to these concepts either respectively or collectively, but the general consensus remained that the terms are ill-defined (Haas et al., 2000).

An attempt was made by Haas et al (2000) to describe each term individually and it is summarised below:

- **Modularisation** - Generally referred to as the preconstruction of a complete system away from the job site that is then transported to the site. The modules are large in size and possibly may need to be broken down into several smaller pieces for transport. Usually more than one trade is involved in the assembly of a module.
- **Prefabrication** - Normally involves one skill or trade, such as electrical, piping, or rebar and can be defined as “a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation” (Tatum et al., 1987). These prefabricated components often only involve the work of a single craft. Any component that is manufactured off-site and is not a complete system can be considered to be prefabricated.
- **Preassembly** - A common definition for preassembly is “a process by which various materials, prefabricated components, and/or equipment is joined together at a remote location for subsequent installation as a unit” (Tatum et al., 1987). The preassembly may be completed at the job site in a location other than the place of final installation and can involve adapting sequential activities into ones that are parallel. A preassembly often contains only portions of systems, and work from a variety of crafts is typically necessary. Preassembly is generally considered to be a combination of prefabrication and modularisation and may use fabricated components made off-site and then assembled near the site. These units can then be installed at the site, similar to modules.

Jaillon & Poon (2009) then furthermore proceed to describe prefabrication as:

> A manufacturing process, generally conducted at a specialized facility, in which various materials are joined to form a component part of the final installation. The manufacturing process may be undertaken in a factory environment (factory prefabrication) or under the open sky at the site (site-prefabrication). The term off-site fabrication is used when both prefabrication and pre-assembly are integrated (Jaillon & Poon, 2009).

The definition above introduces the term 'off-site fabrication' and Gibb (1999) defines this concept as follows:

> Off-site fabrication is a process which incorporates prefabrication and pre-assembly. The process involves the design and manufacture of units or modules, usually remote from the work site, and their installation to form the permanent works at the work site. In its fullest sense, off-site fabrication requires a project strategy that will change the orientation of the project process from construction to manufacture and installation (Gibb, 1999).

It becomes apparent that no single definition exists for these concepts and that finite details distinguishes one from the other, but it does however seem that these terms all adhere to a general theme, namely: Components manufactured in a controlled environment, either on- or off-site and then assembled at the project location.

For the duration of this thesis, the terms above will collectively be referred to as 'prefabrication' and hence all the principles associated with each, will be associated with prefabrication.

2.2.1 Scope of Prefabrication

According to Gibb (1999) most commercial building projects can be subdivided into a number of primary elements, viz.:

- Substructure – *Foundations and work below ground*
- Frame – *The superstructure of the building*
- Envelope –*The external walls and roof that form the perimeter of the building*

- Services – *The mechanical and electrical building services distribution*
- Internal works – *The internal walls, raised floors, suspended ceilings and applied finishes such as plaster, paint, wall coverings, etc.*
- Facilities – *The major parts of the building that are generally provided by the developer for the use of the end-user, such as kitchens, lifts/elevators, plant rooms, toilet/washrooms, etc*.

Appendix A contains a model example which demonstrates the possible extent of prefabrication for a major multi-storey commercial building, referring to each of these primary elements above.

2.2.2 Categories of Prefabrication

Prefabrication, in essence, can be related to every factory manufactured product, but this would cause the term to lose all its meaning, more so with regards to this study. In support of this notion, the more generic and small-scale 'off-site fabrication' is ignored, but rather three types of prefabrication is established by Gibb (1999), namely: Non-volumetric prefabrication; Volumetric prefabrication; and Modular building.

It should be remembered, however, that the dividing line between each type is not immovable, and many applications will involve more than one type.

The three types of prefabrication will now be explored.

2.2.2.1 Non-Volumetric Prefabrication

Figure 2.1 - Precast insulated wall panels (left) (Canadian Precast Concrete Institute, 2005) *and precast concrete column (right)* (Canadian Precast/Prestressed Concrete Institute, 2007).

Since all the units and systems produced will have some volume, the term non-volumetric may be somewhat misleading. Nonetheless, to distinguish it from volumetric prefabrication, it is used to mean items that do not enclose usable space. Non-volumetric elements are typically elements such as slabs, façades and other tilt-up systems **(Figure 2.1)**. Other characteristic examples would include parts of the structural frame or cladding of building, internal partitions, parts of building services, and so on (Gibb, 1999).

2.2.2.2 Volumetric Prefabrication

Volumetric prefabrication covers units that enclose usable space, but do not themselves form the whole building. Only a small amount of work is left to be completed on-site due to most of the units being substantially complete in themselves. Volumetric prefabrication is mainly used for 'facilities' as defined in **2.2.1** above. It includes solutions such as office toilet/washrooms, plant rooms, building services risers, and lifts. These units are generally installed within a new or existing building structure, and do not usually provide any support for that structure.

2.2.2.3 Modular Building

Figure 2.2 - Modular school classroom element (Oldcastle Precast, 2006)

Modular Building comprises units that form a complete building or part of a building, including the structure and envelope **(Figure 2.2).** As with volumetric prefabrication, most units are substantially complete in themselves, leaving only a small amount of work to be completed on-site. Some systems, especially for multi-storey construction, provide only the structure and sometimes cladding, and are then finished on-site. For units that are fully finished off-site this category provides a complete off-site fabricated building – a 'one-stop' system for a client wanting a cost-effective and relatively straightforward building (Gibb, 1999).

2.3 Defining Precast Modular Construction

Prefabrication can be accomplished in virtually any material. Today there are more choices of materials than ever before. With the advent of nano materials and composites, the traditions of concrete and steel may begin to seem historic. However these materials are still high performers for their cost and the reality is that the use ofalternative structural materials outside of these two seem unlikely in the near or long-term future, especially in South Africa (Smith, 2010).

Materials for structures are generally steel and concrete because they are readily affordable and available. Labour crews have been established to handle these materials and their associated systems. Tools, machines, and factories are well established to develop and manipulate steel and concrete and design standards exist for both steel and concrete. In

South Africa these include the National Building Regulations, the South African Standard SANS 10100-1 (2000) for concrete and the SANS 10162-1 (2005) for steel.

As mentioned earlier, precast modular construction is an extension of the ideas associated with prefabrication. Prefabrication however can be linked to any construction material whereas the term precast modular construction is very specific in its composition, i.e. precast concrete. This inherently means that precast modular construction has all the associated principles of prefabrication and modularisation, but with the distinguishing characteristic that all the components are made of concrete.

This might seem limiting in an era where some alternative building methods utilising foam, polystyrene, etc. are appearing. However, to delve deeper into all the available alternative technologies would increase the scope of this study tremendously. So for the purpose of this study/chapter, and to address some social concerns with alternative building technologies (which are discussed in detail in the next chapter), the focus will be on prefabricated concrete components.

Therefore, the theory hereafter follows the logic depicted in **Figure 2.3**. The term 'precast modular construction' is dissected into two parts, namely: Precast Concrete and Modular Construction. These concepts are looked at individually, identifying applications of each along the way.

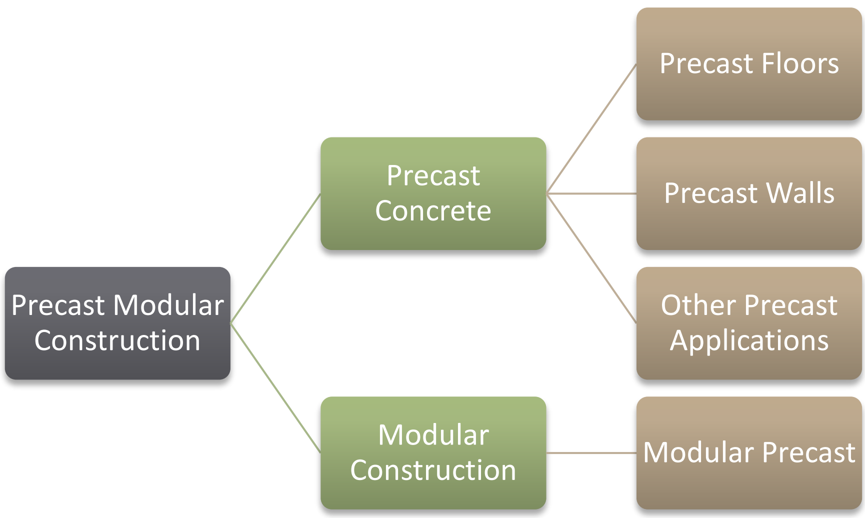

Figure 2.3 – Definition logic of Precast Modular Construction

2.4 Precast Concrete

Precast construction is the casting of concrete components off-site in a plant and shipping to site for assembly, although in the case of tilt-up construction, it can also be done on-site. The Precast/Prestressed Concrete Institute in its 'Designing with Precast & Prestressed Concrete' guide defines precast concrete as follows:

> Precast concrete consists of concrete (a mixture of cement, water, aggregates and admixtures) that is cast into a specific shape at a location other than its in-service position. The concrete is placed into a form, typically wood or steel, and cured before being stripped from the form, usually the following day. These components are then transported to the construction site for erection into place. Precast concrete can be plant-cast or site-cast (Precast/Prestressed Concrete Institute, 2010).

Precast concrete components are reinforced with either conventional reinforcing bars, strands with high tensile strength, or a combination of both. The strands are pretensioned in the form before the concrete is poured. Once the concrete has cured to a specific strength, the strands are cut (detensioned). As the strands, having bonded to the concrete, attempt to regain their original untensioned length, they bond to the concrete and apply a compressive force. This "precompression" increases load-carrying capacity to the components and helps to control cracking to specified limits allowed by building codes (Precast/Prestressed Concrete Institute, 2010).

According to Smith (2010) there exist two primary distinctions in precast: architectural precast and structural precast. Architectural precast refers to any element, whether structural or not, that has a finish which is more than a standard grey. This usually means that precast will be seen, leaving it exposed at building occupancy.

Structural precast on the contrary, is defined by The National Building Regulations (Republic of South Africa, 1998) as: "The system of constructional elements and components of any building which is provided to resist the loads acting upon it and to transfer such loads to the ground upon which the foundation of the building rests."

Precast concrete elements are made with a high early additive and higher concrete class than in-situ concrete so as to achieve high early strengths (Smith, 2010). In addition, the precast process may include adding heat to accelerate the hardening of the concrete and adding moisture for full hydration of the cement and water. Precast plants are able to produce fully cured elements from laying of prestressing or reinforcing strands to removal of finished elements from the beds in a 24-hour cycle. These developments have allowed precast meeting the needs of speed, cost, superior strength and aesthetic variation in construction.

When using concrete construction, the selection of precast over site-cast has obvious benefits. Precast is carried out at ground level where beds may be dispersed and casting occurs concurrently. Mixing and placing concrete in a plant is highly mechanised and carried out in sheltered conditions when necessary. The nature of concrete and of the production methods allows manufacturers to produce standardised elements using pre-set forms and shutters that are endlessly reused. Furthermore, the design and the manufacturing process does not require the temporary supports and scaffolding that are, on more conventional construction sites, waste generating, time consuming and a health and safety hazard (WRAP, s.a.). Smith (2010) states that concrete mixtures used in precast applications are also generally stronger at 35 MPa when compared with on-site concrete at 18 to 25 MPa. Reinforcing steel is also of higher yield strength than normally used in site-cast situations. The large majority of precast today is prestressed.

The erection of precast is similar to that of steel but Smith (2010) argues that it is faster than structural steel framing. It is of course naturally faster than in-situ due to the formwork not being site-customised and curing time taken out of the process. In addition precast can be shaped to form virtually any three-dimensional shape.

2.4.1 Uses of Precast Concrete

Various uses of precast concrete exist such as double and single tees, slabs, panels, beam and girders, stairs, and columns. Total precast structures have begun to feature where architectural and structural precast, prestressed concrete components are combined to create the entire building (Canadian Precast/Prestressed Concrete Institute, 2007).

Precast concrete’s plasticity allows it to be cast into a wide variety of shapes and sizes. Although precast manufacturers routinely produce custom designs and shapes, designers typically take full advantage of speed and economics by using standard components that can be cast and replicated many times with existing forms. To this end, precast manufacturers provide a number of typical components that meet the vast majority of traditional design challenges (Precast/Prestressed Concrete Institute, 2010).

The most commonly used components are discussed below.

2.4.1.1 Precast Floors

In a survey done by Lombard (2011) of 12 structural building precast concrete suppliers in South Africa, it was determined that precast floor systems are the most commonly used structural precast elements in South Africa. Of these, the two most commonly used systems were found to be hollow-core slabs and rib-and-block systems. The reason given by the respondents on why the variety is so small was given as: "To get broader acceptance of the precasting system first" (Lombard, 2011). The Concrete Manufactures Association (CMA) (1999) is of the same opinion and states that 2 basic systems are readily available in South Africa and which designers are familiar with, namely: Hollow-core and Beam-and-block.

These systems can create sturdy floors and decks quickly and efficiently. They arrive at the job site cut to length and already reinforced, where after cranes are used to place them in position on the walls, completing a floor or roof structure in a few hours (Portland Cement Association, 2006). They will be looked at in more detail in the following paragraphs.

2.4.1.1.1 Hollow-Core Slabs

Figure 2.4 - Hollow-core slab (Concrete Manufacturers Association, 1999)

Hollow-core slabs, also known as planks, are used in a wide range of buildings as floor/wall components or where suspended roofs are required **(Figure 2.4).** Their high quality finish and long span capabilities make them ideal for almost any construction project (Jurgens, 2008). These include multifamily and single-family housing, schools, hotels, health-care centres, offices, manufacturing facilities, and other structures. The hollow-core slab is a reinforced or prestressed concrete slab, containing cores, generally varying in thickness from 120 mm to 250 mm (Concrete Manufacturers Association, 2008).

The hollow-core slab is manufactured in the quality-controlled conditions of a factory and the only site work involved is the placing of a levelling screed 30 to 45 mm thick. Hollow-core slabs fitting into non-modular widths (module normally 1200 mm) are cut to size in the factory while concrete is fresh and are cut to length to suit as built building dimensions immediately after the concrete has reached the required strength. Propping is usually not required on hollow-core slabs and following trades can start work immediately after erection (Portland Cement Association, 2006).

Two types of hollow-core slabs are identified by the CMA (2009):

- **Reinforced Hollow-Core Slabs** - Manufactured as wide (900 mm) units, 150 mm deep, incorporating a number of 72 mm cores. Units are made in a range of lengths up to about 7.8 m, and are either taken from stock or manufactured for a specific contract. The wide units need a crane for erection, but spans up to 5 m (depending on the loading) do not necessarily need structural topping or temporary propping, although a levelling screed is required. Structural topping and temporary props are sometimes employed to increase the effective depth used in the design calculation.

- **Prestressed Hollow-Core Slabs** - Manufactured in units 1200 mm wide with depths of 120, 150, 200 and 250 mm. Units are made to order in lengths up to 12 m. The number and disposition of prestressing tendons varies according to span and loading. Occasionally, structural topping is applied to increase the effective depth for superimposed loads. Propping is not generally specified except when the slab is required to act compositely with the structure above, e.g. where heavy walls are carried on the edge of the slab.

Due to the weight saving – up to a third or more – the use of high strength concrete, coupled with prestressing means that hollow-core slabs can achieve considerably larger spans than in-situ reinforced concrete slabs of similar depths (Concrete Manufacturers Association, 2008).

There is however, limited guidance about the design of hollow-core systems provided in the SANS 10100-1 (Jurgens, 2008). Recommendations about the design of such systems are published by the individual South African hollow-core manufacturers (Concrete Manufacturers Association, 2008). Professor Jan Wium, who heads the committee responsible for the revision of the SANS 10100-1, says that South Africa is in the process of transferring to the Eurocode (EN 1992-1:2004), which will be amended to meet South African specific factors and eventually replace the SANS 10100-1:2000 (Wium, 2012).

It is at this point interesting to mention a claim made by Bison, a leading manufacturer of precast concrete floor and wall components in the UK (WRAP, s.a.). Bison claim that for the same floor conditions (spans, loading, etc.), eight cubic metres of concrete would produce 63m^2 of floor area using on-site traditional methods, but using their refined hollow-core system design a total of 808m^2 can be achieved.

The aforementioned presents a plausible argument that hollow-core offers a floor system that is easy to install, uses little resources, does not require expensive and time consuming shutter systems on site, and, more importantly, does not produce waste. However, hollow-core does remain a building technique that is specialised in its implementation, as trained personal are required to operate the cranes, and placement of the slabs require personnel skilled in the workings of hollow-core. There are nonetheless numerous hollow-core specialists in South Africa and each in a different region, providing for ample access to hollow-core options (Concrete Manufacturers Association, 1999).

Some of the various applications and combinations of hollow-core slabs will now be investigated:

2.4.1.1.1.1 Hollow-Core Slab on Cast In-Situ Beams

Figure 2.5 - Hollow-core floor units placed on in-situ beam formwork (Goodchild & Glass, 2004).

When precast concrete is combined with cast in in-situ concrete, it is often termed as 'Hybrid' concrete construction (Goodchild, 1995). Although in-situ will slow down site progress it is mostly used to form homogeneous connections between precast elements and to provide a structural topping for horizontal diaphragm action. In other cases it is used to form the foundations and substructure to the building (fib, 2002).

The advantage of this form of construction is that it removes the need for slab formwork and provides a relatively lightweight floor **(Figure 2.5).** This construction system does not require the involvement of a specialist subcontractor beyond the manufacture and supply of the standard precast units (Taylor & Whittle, 2009).

Previous dissertations have focused on the concept of 'Hybrid' concrete construction (Jurgens, 2008), (Lombard, 2011), (Hanekom, 2011). The focus of this thesis, on the other hand, lies more towards determining *what* is available in terms of precast construction and not in investigating a specific field.

2.4.1.1.1.2 Hollow-Core Slab on Steel-Frames

Figure 2.6 - Hollow-core slab on steel-frame (Concrete Manufacturers Association, 1999).

Most engineers' vision of 'mixed' prefabricated construction is precast concrete floors supported on steel beams **(Figure 2.6)**, often taking advantage of composite action that can be achieved using a small number of shear studs and small quantities of reinforced in-situ infill at the ends of the slabs (fib, 2002).

Hollow-core units of 6-12 metre spans and 150-300 millimetres depths are used mostly in steel frames (fib, 2002). Although this is a concept often used in industrial applications, this method has not had much potential in the South African market when considering school construction, mostly due to the high price of steel..

2.4.1.1.1.3 Hollow-Core Slab on Load Bearing Masonry Walls

A very fundamental application of hollow-core slab is when they are supported on load bearing masonry walls **(Figure 2.7).** Frameless construction comprising brick or block walls of between 90 and 200 mm thickness support the hollow-core slabs (fib, 2002). This concept can be very applicable to a South African market as it still involves a labour intensive task such as masonry, but is combined with the time-efficient method of precast concrete.

Figure 2.7 - Hollow-core on masonry wall (Concrete Manufacturers Association, 1999).

Shukuma Flooring, a hollow-core manufacturer based in Port Elizabeth in the Eastern Cape has constructed many schools in the Transkei using this exact method. Some of the projects utilised hollow-core in the foundation wall as well. Poor availability of raw material and skilled labour in the vicinity of the project was stated as the reason hollow-core was utilised (Shukuma Flooring Systems, s.a.).

Similarly Topfloor, a manufacturer of hollow-core based in Bellvile South, Cape Town, combined hollow-core and masonry for the construction of a school in Ilulandle, South Africa **(Figure 2.8).** Statistics on time and cost were not available. This type of construction is also often seen to be used for apartment buildings in South Africa (Concrete Manufacturers Association, 2008).

Figure 2.8 - School in Ilulandle (Topfloor, s.a.).

2.4.1.1.2 Beam-and-Block

Beam-and-block slabs are made up of precast concrete rectangular shaped beams, the most common beam spacing being 560, 600 and 650 mm. A non-structural hollow concrete rebated filler block is placed between these beams **(Figure 2.9)**. The size of the block determines the beam spacing and provides a flush soffit. A structural concrete topping should have a minimum strength of 25 MPa at 28 days and a minimum thickness of 40 mm. Welded mesh reinforcement is placed in this topping to control possible shrinkage cracks. The filler blocks are available in different heights ranging from 60 mm to 350 mm which produces an overall depth of slab from 110 mm to 400 mm, or more if double blocks are used. This type of slab requires temporary supports at approximately 1.5 m centres, but certain systems can also be designed to eliminate the need for props (Concrete Manufacturers Association, 1999).

Figure 2.9 - Beam-and-Block system (Concrete Manufacturers Association, 1999).

The advantages of this type of slab are as follows (Concrete Manufacturers Association, 1999):

- It provides an economical, versatile lightweight monolithic slab system. Components are relatively light and no mechanical handling is necessary.
- Slabs may be designed as either simply supported or fully continuous.
- They are ideal for soffit plaster but fixing of suspended ceilings is also easy and simple.
- Electrical and plumbing services are readily catered for by omitting hollow blocks at specific locations.

The rib-and-block system is flexible in coping with irregular shapes. Spans are smaller and the lifting capacity required to place beams is less. It is significantly slower than hollow-core slab in construction time however, as in-situ concrete must be poured and cured. Propping of the system during construction is required with a rib-and-block system (Portland Cement Association, 2006).

2.4.1.2 Precast Concrete Walls

Figure 2.10 - Load-bearing precast wall panels (Canadian Precast Concrete Institute, 2005).

Precast walls are panels of concrete cast in a factory or on-site, and are versatile components that can be used as architectural, structural, or combination elements within a building's design. Wall panels can be designed as loadbearing or non-loadbearing components, and can include an inner layer of insulation **(Figure 2.10).**

Non-loadbearing panels can be attached to any type of structural frame, including precast concrete, cast-in-place concrete, or steel. They can be erected in a horizontal position, as in a multifamily housing or office application, or in a vertical position, typically used in warehouse designs (Precast/Prestressed Concrete Institute, 2010).

The panels are connected to the foundation, floors and roof to create the total building structure and are generally rectangular, flat wall sections. They include one layer of reinforced concrete and most also include a layer of foam or other insulating material (Portland Cement Association, 2006).

Documented cases exist in South Africa, specifically Gauteng, where precast concrete panels were utilised, namely: Kaalfontein Ext 22 and Vlakfontein Ext 3. Here the Goldflex 100 & 800 building systems were used to construct 800 and 404 housing units respectively (Chief Directorate: Housing Needs, Research and Planning, 2010).

Agrément South Africa (Department of Public Works, 2008) defines the Goldflex 100 Building System as follows:

> In this system, walls consist of storey-high, large, precast concrete panels joined together. Seven different types of external concrete wall panels are produced. Wall panels may be combined to form factory-assembled three dimensional units, each unit comprising one or more rooms. Alternatively, wall panels may be transported to site individually and assembled there. Combinations of units and individual panels may be used. Foundations, surface beds, finishes, ceilings and services are conventional. Roofs and cladding are either of conventional timber truss construction or precast, reinforced concrete slabs, with or without a parapet (Department of Public Works, 2008).

In addition, the Goldflex 800 Building System is defined as follows:

> In this system the walls consist of large, storey-high, precast, reinforced concrete wall panels which are bolted together to form single storey and multi-storey structures up to ten storeys high. External and internal walls are generally loadbearing, although certain external and/or internal walls may be non-loadbearing. The wall panels on the ground floor are erected on conventional foundation walls or concrete plinths on conventional foundations. Wall panels on the upper floors are erected on cast in situ reinforced concrete floor slabs or on composite floor slabs consisting of a precast, reinforced lower portion and a cast in situ upper portion. Columns, beams, staircases and landings may be of precast reinforced concrete or may be cast conventionally in-situ. Roof construction and coverings, ceilings, floor and wall finishes and all services etc., are conventional (Department of Public Works, 2008).

Variations and application of precast concrete wall panels are discussed hereafter.

2.4.1.2.1 Hollow-Core Wall Panels

Although most often used for flooring purposes, the Concrete Manufacturers Association (2008) has known examples of how hollow-core panels have been used for various walling purposes in South Africa.

Figure 2.11 - Potato warehouse in Delmas using pre-stressed hollow-core slabs (Concrete Manufacturers Association, s.a.).

One such example was in the construction of a Potato warehouse in Delmas, South Africa **(Figure 2.11).** This fast-track project used pre-stressed slabs as retaining walls for the construction of two large potato sheds. 1 100m² of wall slabs were erected in 11 working days - the wall contractors being on site for a total of two weeks. The two steel-framed buildings were supported on piled foundations and the precast, pre-stressed panels were slotted into the webs of 6 m steel columns (Concrete Manufacturers Association, s.a.).

Another example exists in Bloemfontein, South Africa, where two walls were constructed to safeguard military equipment, using hollow-core slabs measuring 4 x 1.2 m. The project reported cost savings of approximately 50%, in addition to the time savings, than had the walls been cast on-site (Concrete Manufacturers Association, s.a.).

2.4.1.2.2 Sandwich Panels

Figure 2.12 - Precast sandwich wall panels (Canadian Precast/Prestressed Concrete Institute, 2007).

When a precast concrete wall contains a layer of insulation, it is referred to as a 'Sandwich Panel' **(Figure 2.12).** Sandwich panels themselves divide into two groups: the full sandwich and the half sandwich. Full sandwich panels have a layer of foam insulation in the middle and a layer of concrete on each face. The layer of concrete on the inside face is reinforced with rebar and has a structural role. It is usually 12 to 20 centimetres thick. It supports most of the vertical loads of the building. The outside concrete layer serves as the exterior finish and protects the foam and may be only 5 centimetres thick. Connecting the two concrete layers are steel or composite plastic struts or pins which extend through the foam. Half sandwich panels have a layer of concrete on the outside only which is reinforced and structural, while the foam layer is on the inside. Most half sandwich panels also have wood or light-gauge steel 'studs' running vertically up the face of the foam (Portland Cement Association, 2006).

Historically favoured for industrial buildings such as distribution centres and warehouses, sandwich wall panels' range of finishes and benefits is expanding the component's applications to schools, retail, residential, office, and other uses (Precast/Prestressed Concrete Institute, 2010).

2.4.1.3 Other Precast Uses

A variety of components can be fabricated from precast concrete, meeting a range of project needs. Customized pieces, sizes, and shapes can be created in many cases to meet specific programmatic needs. The designer should consult with the local precast manufacturer early in the design phase to determine what components will work most efficiently and to review specific sizes, joint locations, and other details that can create cost effective options.

Some other common uses of precast concrete, in addition to those mentioned above, include (Precast/Prestressed Concrete Institute, 2010):

- **Columns** - Typically support cross members such as beams or panels. Traditionally square or rectangular in profile, they are usually cast as multilevel components ranging in length from a single story to six or more levels.
- **Beams** - Horizontal structural members that support deck components such as double tees and hollow-core slabs. Three types cover the majority of uses: rectangular beams, inverted tee beams, and L-beams.
- **Double Tees** - These components are used primarily as deck, floor, and roof components, contributing in large part to precast concrete's ability to create long spans and open interior plans. They can be used for any type of building but most often are used in parking structures, office buildings, and industrial facilities.
- **Piles** - Pilings are used to support structures in poor soil conditions, especially in marine environments, due to their excellent adaptability and resistance to corrosion. Smaller pile sizes, 25 to 35 cm, are typically used for building projects such as convention centres, hotels, and other large facilities.
- **Stairs** - Precast concrete stairs can be used in any application where a stair tower or individual steps are required. They are fabricated either in an open-Z configuration, in which the upper and lower landings are cast in one piece along with the tread/riser section, or as shorter components consisting of only the tread/stair section supported by separate landing components.

The most commonly used precast elements in South Africa was earlier identified as precast floor systems, but other elements such as precast beams and columns can be manufactured in South Africa on request, but this is not often the case. The same applies to structural precast walls, which are very rarely specified in South Africa. An example exists in the Volkswagen paint shop in Uitenhage, completed in 2006. Here precast columns and beams were used, one of the first projects of its kind (Jurgens, 2008).

2.4.1.3.1 Tilt-Up Construction

Figure 2.13 - Concrete panel being raised (tilted) into position (Gibb, 1999).

Although not a factory produced precast element, seeing as it is completely site-cast, this system still utilises concrete and the principles of prefabrication and precast concrete apply. Tilt-up is a form of load-bearing construction which consists of simple on-site casting of large but slender reinforced concrete panels, in some cases columns and beams, on a building's in-situ concrete floor slab. The in-situ slab is constructed conventionally and a bond-breaker is applied to the surface. Formwork for the panels is laid and cross-braced for stability. Lifting points and reinforcement are then installed and the concrete placed **(Figure 2.13).** Panels can be laid individually, in a continuous strip, or stack cast on top of each other. When the panels are strong enough, usually after several days or a week, props and lifting devices are fitted and each panel is lifted (or tilted) until vertical and moved to its position in the perimeter wall. The panels are then propped and finally joined to the floor or roof beams, at which point they are self-supporting. Gibb (1999) states that the tilt-up work typically represents between 25% and 40% of the overall construction cost, depending upon the building services content, etc. Therefore cost reduction in the tilt-up work should significantly reduce the overall project cost.

A documented South African example where tilt-up construction was implemented is the construction of the Hillfox Power Centre, a shopping centre in Roodepoort. This project used tilt-up construction which was chosen by the project team to provide both cost and time savings. The project reported actual cost savings of around 6% and time savings of 3%. The R42 million, 10-month project saved R2.5 million and one and a half weeks on the program, which are significant (Gibb, 1999). This reduced the overall project program enabled earlier letting of the centre and hence early revenue for the developer.

Another example is the Zevenwacht Shopping Centre in Kuilsrivier. Tilt-up was selected due to the power floated finish of the tilt-up panels deemed far superior by the project team, in both quality and durability to the steel floated finish that would have been attainable with a brickwork and plaster alternative. Tilt-up on the 40 000 m^2 retail centre was able to achieve the aesthetic relief features required by the architects economically, accurately and of a high quality (Cement & Concrete Institute, s.a.).

Other examples of tilt-up applications include the:

- Gateway Shopping Centre, Durban
- Sibaya Casino, Durban
- Umlazi Mega City, Kwazulu-Natal

2.5 Modular Construction

2.5.1 Definition of 'Modular'.

All uses of the term modular refer in some way to a self-contained component of a system which has a well-defined interface in relation to the other components. This term, however, has been co-opted by many disciplines, each giving it their own shade of meaning. Modular has discreet meanings in non-construction related disciplines. Further complicating matters, even within the construction environment the terms modularity, modular design, modular home, modular constructivism, modular construction, and just plain modular each have their own subtle meanings.

Finally, even when the term "modular construction" is understood to have the correct definition, it carries with it a wide variety of connotations. Modular may be ugly homogeny to some and contemporary refinement to others. Modular buildings, simply stated, are volumetric components of a building which are manufactured in a factory, and transported to the site on a flatbed trailer and erected into a finished building (Kullman Buildings Corp., 2008).

The Modular Building Institute (2010) defines Modular Construction as: “A resource efficient, off-site delivery method to construct code compliant buildings in a quality-controlled setting.”

Smith (2010) defines modular construction as a standardised unit of construction that is designed for ease of assembly, tends to be more finished than other methods of prefabrication, but it is not restricted in scale. Modules that are larger may be able to have greater levels of finish, but restrict the flexibilty of the overall building when compared to smaller modules which, when arranged, can produce customization of an overall composition.

Modular applications specifically in precast concrete will now be examined.

2.5.2 Modular Precast

Figure 2.14 - Typical Precast Module Section (Endicott, 2000).

Complete precast concrete modular units have traditionally been used for prison construction, but their uses are expanding to include schoolrooms and other applications where large quantities of similarly sized and outfitted rooms are needed to meet tight deadlines. These modules can be designed for structures from one to twelve levels (Precast/Prestressed Concrete Institute, 2010).

The ability to cast the modules and outfit them with many of their required mechanical systems and trappings—including plumbing, electrical, beds, mirrors, and windows—have made them especially popular for prison facilities. The modules are cast as single- or multi-cell units, with as many as four cells in one monolithic component **(Figure 2.14).**

Modules of comparable size to wood or steel, maximising the truck bed, can weigh between 18 and 65 tons depending on the length of the module. Heavy-duty craning equipment is necessary for assembly in precast, often making this option cost prohibitive for residential and light commercial construction.

The commercial modular industry can be separated into temporary modular and permanent modular structures. Temporary commercial modular include construction site trailers, portable classrooms, communication pods, and show rooms (Smith, 2010).

Lewis (2012), Chief Director of Physical Resources in the Western Cape Education Department, said that the only current usage of modular units is in providing temporary solutions for classrooms while construction continues on the school premises. In some instances, administration difficulties can mean that these temporary units remain for a year or more.

Permanent modular buildings, on the other hand, include multistory, multifamily housing, health-care facilities, hotels, government buildings, schools, and other building types developed in traditional on-site construction. The limitation to the size of commercial modular is only in the experience, preference and capabilities of the project team (Smith, 2010).

Although dimensional requirements for modular construction are generally determined by transportation restrictions in each country, some rules of thumb have been assembled (Smith, 2010):

- Module Width
  - 4m Common Maximum
  - 5m Oversized Maximum
- Module Length
  - 16m Common Maximum
  - 18m Oversized Maximum
- Module Height
  - 3.5m Maximum
- Building Height
  - 1 to 3 Stories (Wood Modular)
  - 5 to 12 Stories (Steel Modular)
  - 12 to 20+ Stories (Steel and Precast Specialised Modular).

Design codes and standards are discussed in the next section.

2.6 Design Guidelines

Currently South African standards for structural design are based on those of different countries. For instance, the SANS 10162:2005 (The structural use of steel) is based on the Canadian Standard whereas the SANS 10100:2000 (Code of practice for the structural use of concrete) is based on the old British Standard. However, the South African building standards are in the process of being modified and will eventually be based on the Eurocodes (EN 1992-1) (Wium, 2012).

The SANS 10100, although based on the British BS 8110, has been adapted to the South African environment. The EN 1992-1 also partly evolved from the BS 8110. It is seen that the clauses relating to precast construction in the SANS 10100-1 and the EN 1992-1 are very similar. Both clauses state that a precast design should firstly satisfy the general design requirements. The codes then continue to state several considerations that should be incorporated into the precast design of the structure.

As can be seen in **Table 2.1**, the topics that are treated in the SANS 10100-1 and the EN 1992-1 are very similar. The presentation, layout and explanation of the design concepts are however very different.

Description	**SANS 10100**	**EN 1992**
Glossary of precast construction terms		X
General rules for manufacturing and transient situations	X	X
Effect of heat curing on concrete strength development		X
Effect of heat curing on creep and shrinkage		X
Effect of heat curing on prestressing force		X
Structural analysis includes the structure's behaviour during all stages of construction	X	X
Structural analysis includes the actual and theoretical behaviour of connections	X	X
Structural analysis includes alignment deviations during construction	X	X
Consider effect of horizontal movement on structural integrity		X
Restraining moments in precast slab topping	X	X
Restraining moments in hollowcore slab by placing reinforcement in open cores		X
Wall to floor connection reinforcement design	X	X
Obtaining shear transfer between precast floor elements	X	X
Considerations for achieving diaphragm action in a precast floor		X
Tying systems	X	X
Placement of transverse reinforcement in slabs	X	X
General rules for connections transmitting compressive forces	X	X
General rules for connections transmitting shear forces	X	X
General rules for connections transmitting bending moments or tensile forces	X	X
General rules for connections with structural steel inserts	X	
General rules for shear in interfaces	X	X
General rules for half joints and detailing	X	X
General rules for reinforcement at supports	X	X
Designing Bearings	X	X
Designing pocket foundations		X
Designing corbels	X	X
Specific design of vertical elements to prevent progressive collapse	X	

Table 2.1 - Comparing the precast sub-clauses of the SANS 10100-1 and the EN 1992-1.

The EN 1992-1 is found to be more up to date with current international precast design practices. The design of precast floors differs significantly between these codes. The EN 1992-1 focuses on the overall design of hollow-core slabs for effective diaphragm action. The SANS 10100-1 neither covers hollow-core units nor the design of diaphragm action in a floor without a structural topping. The EN 1992-1 also has several highly detailed sketches to aid the user in understanding certain concepts.

SANS 10100-1 however is better in one instance in that it clearly states that the engineer should design the overall structure to prevent progressive collapse should a vertical support (i.e. a column) fail, whereas the EN 1992-1 merely states that the structure should be "robust." Overall though It becomes apparent that it may be necessary to upgrade the SANS 10100-1 if precast concrete construction is to achieve its full potential in South Africa, as the current South African standard is less comprehensive than that of the Eurocode.

In terms of design guides and manuals other than standards, Blismas et al. (2005) identified the unavailability of guidance for off-site manufacturing as one of the barriers of precast construction. Jurgens (2008) found that in many countries design guides are available and suggested that such a guide for South Africa might improve the use of precast concrete in the country. The alternative for South African designers at the moment is to use international guides and standards for a comprehensive precast design.

It is concluded that South African design standards need to be updated to include all the aspects of precast concrete design and it would be beneficial to have a design guide for precast elements.

In support of the initial hypothesis, precast concrete usage in the school sector is discussed in the next section.

2.7 Precast Construction in Schools

Although South Africa has been slow to adopt the precast mentality, internationally precast concrete has been a favoured material for school, college and university building structures, providing design flexibility and fast construction (Canadian Precast/Prestressed Concrete Institute, 2007). Precast concrete offers architects, owners, and contractors a number of important benefits. Chief among them is the speed with which it can help complete both design and construction activities in an industry where time is paramount (Paterson, 2009).

In addition to classroom and office facilities, student residences, auditoriums, gymnasiums and school swimming pools have been constructed using long span precast concrete floor and roof members. **Appendix C** contains several case studies of where precast concrete was successfully implemented in the construction of schools.

The case studies investigated achieved amongst other things the following:

- The project team delivered a $1.35 million (R12 million) building in 108 days from contract signing to completion by using modular precast concrete elements. *(Case Study 1)*
- Both structural precast, prestressed concrete and architectural precast concrete members were used very effectively to build a two-story, 3070 m^2 swimming pool facility. *(Case Study 2)*
- A precast concrete panel wall and hollow-core slab system was used for the rapid construction of a two-storey 420 pupil primary school. *(Case Study 3)*
- Designers used precast insulated sandwich wall panels, hollow-core flooring and precast concrete columns and beams to rapidly construct two similar 35 000 m^2 high schools. *(Case Study 4)*

These case studies strive to illustrate that educational buildings can be designed using architectural and structural precast concrete components that include **(Figure 2.15)**:

- Load-bearing and non-load-bearing precast concrete wall panels
- Hollow-core and double tee floor/ceiling slabs
- Precast columns and beams

Figure 2.15 - Precast wall panels and hollow-core floors during the construction of a school (Canadian Precast/Prestressed Concrete Institute, 2007).

The Precast/Prestressed Concrete Institute (2010) provides a list of challenges/factors which are important from an education perspective during construction and after when the building is used and explain how precast concrete directly addresses these factors **(Table 2.2)**.

Design Challenges	Precast Concrete Solutions
Meet strict budgeting needs based on tax revenues.	A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single source responsibility from the precast manufacturer, saving costs throughout the construction process.
Ensure that the building is ready for the school year or to meet other deadlines.	Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared. Year-round, all-weather construction ensures that schedules are met.
Maximize interior floor space.	Insulated sandwich wall panels offer an efficient, thin cross-section that maximizes interior floor space while minimizing the footprint.
Create needed long-span areas, such as gymnasiums and pools.	Hollow-core slabs and double tees can span long spaces to minimize or eliminate columns where needed.
Provide for future addition or expansion of classroom spaces.	Expansion can be accomplished by removing end panels and adding new panels onto sides. Original mixtures and aggregates can be replicated in added panels.
Create a highly fire-resistant structure.	Inherently non-combustible composition, along with compartmentalization designs, contains fire to specific areas and allows for detection, evacuation, and suppression.
Minimize operating costs throughout the life of the building.	Minimized joints, compared with brick or block construction, require less maintenance throughout the building's life. Insulated sandwich wall panels provide high levels of energy efficiency, reducing air-conditioning costs.
Minimize congestion and safety concerns on site and in the general vicinity during construction.	Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during construction.
Provide a strong, institutional look that conveys an educational image.	Architectural precast concrete panels use colours, textures, reveals, finishes, form liners, or thin brick insets to match any needed design style. School names, emblems, and other custom touches can be embedded into panels, creating unique accents.

Table 2.2 - Precast concrete solutions to design challenges faced by schools (Precast/Prestressed Concrete Institute, 2010).

School buildings have inherent features which are well suited to a prefabricated approach and hence a school building initially designed as a total precast system can provide the best complete solution possible. This notion is investigated in more detail at later stages in this study. Precast concrete as seen in **Table 2.2** accounts for many conditions important to educational institutions, and as a whole provides many time, cost and quality benefits which are discussed in more detail in the next chapter.

2.8 Conclusion

This chapter attempted to define the concept of Precast Modular Construction, by separating it into two parts, namely: Precast Concrete and Modular Construction. These concepts fall under the general theme of prefabricated construction, and the term 'prefabrication' was hence first defined.

Prefabrication was determined to be a manufacturing method whereby structural building components are manufactured off-site, and in some cases on-site, to be shipped and then erected on-site. To assist in defining a clear scope for this study, prefabrication was limited to concrete applications. Precast concrete was therefore looked at in more detail. Various uses of precast concrete were investigated, ranging from floor and walls to beams, columns and tilt-up construction. Modular units manufactured from concrete were discussed so to completely define the title.

It was found that non-school examples of applications of each variant could be found in South Africa, for all but precast modular. On the contrary, examples exist for all applications internationally, especially in school construction. Precast concrete was additionally found to directly address issues paramount to education sectors. As evidence, 4 case studies of international projects - contained in **Appendix C** - aimed to showcase how the aforementioned components were successfully utilised in constructing a school. It becomes clear from the said case studies and information in the last section, that the initial hypothesis is indeed very plausible, in that Precast Modular Construction is a viable alternative to traditional construction methods of schools. Barriers to why South Africa might struggle to follow this trend, is gradually discussed throughout the subsequent chapters.

In addition, design codes and standards were briefly discussed. It was found that the South African standards were less comprehensive than the equivalent Eurocodes regarding precast concrete construction. An update of the current SANS is recommend, which coincidently is in the process of taking place. The SANS is en-route to be replaced by the Eurocode, which could potentially result in improved guidance in the utilisation of precast construction techniques.

In conclusion, it was not the purpose of this chapter to provide an opinion or recommendation on which system or combination of systems is best suited for school construction. The rationale behind this being that each project is unique in its location, goals and scope, and that a precast system should be tailored to each specific project by the relevant designers and contractors. For that reason, this chapter merely attempted to identify *what* is available to these parties, and how to use or combine them, is regarded as the prerogative of the project team. The chapter did establish though that Precast Modular Construction is an effective and feasible alternative.

There is however thought an 'ideal' solution to utilising precast construction and this is referred to as 'total-precast concrete systems' (Precast/Prestressed Concrete Institute, 2010). These combine a variety of precast concrete components into an entire structural system. Typically, this includes precast concrete columns, beams, and wall panels to create a structural frame, hollow-core slabs or double tees as span members, and wall panels as a cladding. The design can save material, labour, and scheduling costs by combining several components, both architectural and structural, into one piece. **(Appendix C)**

Lastly, prefabrication, and with respect to this study 'prefabricated precast construction', has many inherent advantages. These will be looked at in the succeeding chapter. More specifically, how prefabrication implicates time, cost, quality, socio-economy, logistics, health and safety, and the procurement strategy.

Chapter 3

Implications of Using Precast Modular Construction

3.1 Introduction

Each construction project has a number of key principles that it must adhere to. Although not all of the issues may be critical for a given project, generally, a project must respond to the following principles of construction and their effect on productivity (Smith, 2010):

- Time
- Cost
- Quality
- Labour
- Scope
- Risk

The client's priorities regarding the project will determine how much emphasis is placed on these principles. Given that the Government is the client when considering school construction, an optimal balance is sought between the above aspects. Whether prefabrication has the potential to provide, or thwart, this balance is investigated in this chapter.

The preceding chapter aimed to define exactly what is meant by precast modular construction. This chapter now builds on this theme by discussing the characteristics, how prefabrication affects the above principles and attempts to answer the question: 'Why should we, or should we not, use prefabrication on our project?' The principles will now be discussed individually.

3.2 Time

The main benefit of prefabrication is a reduction in the on-site program duration. This is achieved by the overlapping of off- and on-site activities which would be done in sequence using traditional methods (Gibb, 1999). Prefabrication essentially takes work away from site and into the factory, thus reducing the duration of operations critical to the overall program on-site. Precasting is not constrained by site progress or conditions and can continue independently of on-site operations whereas site work is traditionally vulnerable to disruption from extremes of weather (Goodchild & Glass, 2004). By using prefabrication the site will be vulnerable for less time and so the risk of delay and requirements for protection will be reduced for a given project (Phillipson, 2001).

Additional time may be spent in the design phase on complex projects to coordinate the use of prefabrication and modularisation, but the time saved on-site typically makes up for this (McGraw-Hill Construction, 2011).

A research study (McGraw-Hill Construction, 2011) of 809 construction industry professionals was undertaken in the United States to assess the level and scope of the use of prefabrication construction processes. One significant productivity finding from prefabrication users was that 66% reported that project schedules decreased and 35% claimed by 4 weeks or more. This figure is very much subjective, but nevertheless provides an idea of what was achieved.

Warszawski et al (1984) conducted a study in which construction alternatives were evaluated for a residential four-story building with four identical apartments on each floor. Each apartment had a gross area of approximately 94 m^2. The use of precast wall panels or precast slabs reduced the construction time of a 16 dwelling building by one month, and the use of both elements simultaneously reduced it by 4 months. The total project duration, however, was not mentioned.

Similarly, a chart provided by the Precast Concrete Institute (Shutt, 2003) compares precast concrete designs with typical masonry designs of recent projects in the Southeast of the United States to show the value that precast concrete can provide, both short and long term **(Table 3.1)**. The chart includes in two cases cost savings as well, which is relevant to the next section where the cost advantages of prefabrication are discussed. Overall, between 2 and 4 months were saved on the construction schedules of the respective projects.

School Type	*Precast Design*	*Masonry Design*	*Typical Precast Advantage*
Elementary school with 4400 m^2 of exterior wall area	800 m of precast panels with inset brick	20cm CMU with brick	2 months faster Saves $.40 to $.50 per sq. ft., (R3.6 to R4.5 per m^2)
Elementary school with 2000 m of interior wall area	Interior non-load- and load-bearing insulated panels	Concrete block	4-months' time savings
Middle school with 53 000 m^2 of exterior wall area	Insulated sandwich wall panel with inlaid brick	20cm CMU with brick	4 months faster enclosure Saves $.35 to $.40 per sq. ft., (R3.15 to R3.6 per m^2)
Middle school with 2000 m of interior wall area	Interior non-load- and load-bearing insulated panels	Concrete block	4-months' time savings

Table 3.1 - Precast Design vs Masonry Design (Shutt, 2003). *(CMU = Concrete Masonry Units)*

Faster programmes mean the client will obtain the facility at an earlier date and hence it can be used for its intended purpose earlier (Gibb, 1999). This fact is extremely relevant to school construction where learning environments are needed quickly and project deadlines are frequently inflexible. According to Lewis (2012), the current contract period for the construction of a school in the Western Cape is approximately **14 months**, but expecting this to be reduced to 7/8 months if prefabrication is implemented.

This figure, however, of 7/8 months might seem more optimistic that what is actually possible in practise. Compared to the earlier mentioned examples and survey, a realistic figure appears to be between 4 weeks and 4 months.

Furthermore, the amount of time saved on a project is also very dependent on the material and extent of prefabrication utilised. The Modular Building Institute (2010) claims time savings obtained from using a complete modular solution can be between 30% and 50%. This modular solution, however, is a product of steel frame construction and not precast concrete. It therefore, due to the earlier scope definition, falls outside the scope of this study and does not have to be considered. Nevertheless, complete use of steel frame modular construction has shown to reduce project duration by almost half (Modular Building Institute, 2010).

3.3 Cost

Project cost is inextricably linked to project time (Goodchild, 1995). Reduction in project time leads to reductions in the overall cost to the client. This is achieved by providing income generation at an earlier date than what would be possible with a conventional construction approach (Gibb, 1999). Traditionally, cost is the most influential factor in the choice of frame material. Although the structure of a building represents typically only 10% of construction cost, the choice of structural frame material can have dramatic effects on the cost of other elements of construction – such as external cladding, services and internal planning (Goodchild & Glass, 2004).

In addition to the benefits from a shorter site duration, there will be savings by effectively reducing the extent of site activities (Gibb, 1999). Reliance on on-site labour is reduced along with the ability to avoid overtime pay, other unexpected labour costs and the ability to reduce on-site resources required.

There is also the value of having a guaranteed, fixed cost (McGraw-Hill Construction, 2011). Traditional construction projects are infamous for their increases due to variation during the construction process. Even when prefabrication appears to be slightly more expensive from the outset, the avoidance of unexpected costs during the process is valuable, especially for owners with inflexible budgets such as those in the public sector. According to Willemse (2011), the Department of Transport and Public Works in South Africa allow for a 20% margin in which the project may exceed the contract price.

Gibb (1999) provides a list of items that should be considered when evaluating prefabrication against traditional construction:

Potential additional costs:

- Real costs of fabrication facility
- Additional costs from large capacity transportation
- Additional costs from increased capacity of site craneage

Potential cost savings:

- Productivity cost savings from prefabrication
- On-site cost savings due to shorter construction period
- On-site cost savings due to less on-site work
- On-site savings due to fewer construction workers
- Cost savings from reduction in unplanned on-site remedial works

Smith (2010) provides a similar list in which he mentions some of the hidden costs associated with prefabrication. These include:

- **Overheads**: Manufacturing facilities employ full-time staff and have facility costs such as equipment purchase and maintenance, renting space and monthly utilities. Therefore, a profit margin must be set so as to cover these overheads, which can potentially push up costs.
- **Transport**: Transportation due to prefabrication is higher per unit volume because of the chunking of the panels, modules and components that are often shipped with more air than tightly packaged, on-site erected materials and products. Logistics is discussed in more detail in **3.6** of this chapter.
- **Setting**: Prefabrication may also require larger cranes, increasing the cost for construction. Also, craning a prefabricated element can be awkward and require skilled labourers or dedicated crews to place the elements.
- **Design fees**: As prefabrication requires more coordination with construction and fabrication teams, architects and engineers may charge higher rates for the investment of time.

Prefabrication does not necessarily mean a reduction in overall project budgets but does mean a reduction in project schedule and improved quality. At Aldercastle, a successfully completed office building in London, traditional in-situ brickwork would have been cheaper than precast on a purely elemental basis, meaning savings of approximately £300,000 (R3,9 million). However, the project team argued that value for money could not be determined purely from the bottom-line tender prices, but from a genuine assessment of a contractor’s resources, experience and team (Interface, 1999).

On this project, the project team felt the downstream benefits of precast outweighed the higher initial cost. Considerable savings were achieved on preliminaries due to a quicker build period, and further savings were made on external scaffolding which was not required as all the panels and windows were designed to be fitted from the inside (Interface, 1999).

For projects in which cost is of concern, as with the majority of public works, prefabrication must be employed intentionally and with a high degree of planning (Smith, 2010).

3.3.1 South African Context

At present, the Western Cape education department is expected to receive R14.2 billion for the 2012/13 financial year. The Western Cape's budget compares with R26.2 billion allocated in the Eastern Cape for education, R34.7 billion in KwaZulu-Natal and R10.04 billion in the Free State (SAPA, 2012). It is apparent then that there is a clear intention by the authorities that large amounts of funds are required to address issues in the education sector.

As mentioned earlier, prefabrication presents a guaranteed, fixed cost to the client and to clients with conservatively flexible budgets, such as the Department of Public Works, prefabrication is in this regard more advantageous than traditional methods. Even though it does not necessarily mean a decrease in overall expenditure when compared to traditional methods, it does guarantee improved project schedules **(Table 3.1)**.

Furthermore, attempts have been made to measure the cost of a prefabricated solution against that of a traditional solution from a South African perspective (Jurgens, 2008), (Lombard, 2011). In a study done by Jurgens (2008), a theoretical office building was identified to be considered in the case study. The building consisted of a total floor area of 900m^2 and was conceptually designed, priced and scheduled according to the In-situ beam and slab, Hybrid Concrete Construction and In-situ flat slab construction methods. Hybrid Concrete Construction (HCC) was found to be slightly less expensive than other construction methods for the Office Building of more than 10 storeys. The costs considered included only the material and erection costs. HCC was also found to be significantly faster than other construction methods for the Office Building of more than 3 storeys. These results, however, remain theoretical.

Additionally Lombaard (2011) did a comprehensive investigation on what the lifetime costs of a precast system would be compared to an in-situ system. Overall project costs were also explored and a scheme was developed to try and compare various construction alternatives. In short, precast systems were almost always found to give similar financial results to traditional systems. For more detail, one can refer to the specific document (Lombard, 2011).

A cost comparison, however, will be very dependent on factors such as the socio-economic and construction climate. Actually, for this reason it may not be able to do a cost comparison. The best way would be to allow contractors to tender and to propose their own construction method. If precast is cheaper, then it will show in the tenders.

In addition, should the Department of Public Works ever consider a prefabricated approach, it should be determined to what extent they are willing to commit financial resources to address the issues at hand. If indeed they feel prefabrication is the right avenue, then a feasibility study should be instigated internally or by an external party who has experience in the prefabrication field.

3.4 Quality

Prefabrication is a product which stems from a climate-controlled environment using efficient equipment operated by well-trained people (Wong et al., s.a.). Factory controlled conditions mean a better quality of build, better finish and fewer defects. These advantages are matched by those for the skilled workforce who are carrying out the work – a temperature controlled and enclosed workplace using production line techniques that significantly reduce the risk of accidents and ill health (Taylor, s.a.). Quality control and assurance procedures are easier to apply in the factory environment. It is far easier to let concrete be moulded in previously fixed factory moulds, than fit shuttering to in-situ work (Goodchild, 1995).

McGraw-Hill (2011) claims that, even though no compelling cost benefit is found by using prefabrication, clients often choose to use it because of the dependable quality. This, however, does not mean that all on-site work will be substandard, nor even that all prefabrication will necessarily be of a superior quality, as there are many other factors to consider (Gibb, 1999).

The careful quality control of manufacturing processes also enables waste to be controlled and minimised through appropriate design and recycling opportunities. In addition the use of prefabricated components should cut the volume of site spoilage associated with current practices of over-ordering and poor site handling for the equivalent traditional processes (Phillipson, 2001). On the contrary, prefabrication is sometimes prone to specific quality issues.

The South African Bureau of Standards (SABS) was established in terms of the Standards Act no. 24 of 1945. In terms of the latest edition of the Standards Act no. 29 of 2008, it operates as the national institution for the promotion and maintenance of standardisation and quality on commodities and services. Suppliers are urged to accredit their company and products to the SABS 1200 (or the new edition SANS 2001) or ISO 9000 standards. To qualify for the accreditation, suppliers are audited according to their compliance to a wide range of pre-determined specifications. A substantial fee is required from the suppliers prior to the audit. Once accredited, it ensures that the supplier produces superior quality product that can be used in the industry (Concrete Trends, 2010).

The Concrete Trends (2010) magazine explains that although some suppliers implement these standards in their products, many suppliers are not overly concerned by these standards. Suppliers claim to manufacture their products according to these specified standards, but ignore the accreditation process of their products because of the financial costs involved. Others are simply not interested in the accreditation process for other unknown reasons.

These suppliers are hence able to supply products at lower costs per unit. This immediately provides these suppliers with an advantage over accredited suppliers when costs are compared (Concrete Trends, 2010). Suppliers that do not accredit their products are under the impression that if they are "not obliged to accredit their products" and the industry and clients do not request accreditation, it is not worth the effort and money (Angelucci, 2012).

Some of the hazards associated with constructing with these unaccredited elements are the possibility that substandard materials are used, shortcuts are taken with production methods, immediate or latent defects occur and the industry loses confidence in precast elements that in turn gives a negative image to the precast industry (Concrete Trends, 2010).

Other potentially problematic issues can occur in the form of damage to the precast components during either placing or during transportation, but these can be negated to a certain extent if transport and placing is undertaken by an experienced party. In the case of on-site precast work, such as tilt-up construction, the process is also subject to damage incurred during placing. However, tilt-up construction is a field requiring well experienced individuals and work is predominately carried out under controlled and supervised situations. At present, there is a single experienced tilt-up specialist in South Africa, 'Tilt-Up Systems CC', who is responsible for more than 15 successful local tilt-up projects thus far.

3.4.1 South African Context

In South Africa, some engineers have the opinion that the level of quality of construction in any method is the reason why precasting is not the preferred method of construction. Lombaard (2011), in response, set out to test this statement by investigating the following three issues:

- Specification of element quality in the South African Standard – *This seems to be adequate.*
- Specifying details regarding quality on construction drawings – *This seems to be satisfactory as determined by a small survey.*
- Quality control or quality management of construction work: - *This seems inadequate in general.*

Lombaard (2011) further explored these points, in conjunction with a pair of field studies, and overall it was found that non-compliance with building regulations, i.e. SANS, was the prevalent problem in the South African industry. The study can be referred to for further information.

Alternative building methods, therefore, generally have fallen into a stigma of inferior quality. This in part due to cases where housing units had to be demolished as a result of poor workmanship (Chief Directorate: Gauteng Provincial Department of Local Government and Housing, 2010). Studies conducted in both 2003 and 2010 by the Department of Human Settlements, found that within a few months after construction of low cost houses were completed structural defects such as gaping wall cracks, roof leaks, unstable roofs, water penetration and seepage were experienced (Chief Directorate: National Department of Human Settlements, 2010). All these problems contributed to already negative perceptions of alternative building technologies which prevented large scale rollout.

Although monitoring and quality assurance is important in all construction projects, the two are even more vital when the construction is innovative or using alternative building technologies. The Chief Directorate: Gauteng Provincial Department of Local Government and Housing (2010) suggests that as a remedy, it is important that both the NHRBC and Agrément be part of the monitoring of government housing constructed with alternative materials or innovative systems in order to protect the consumers.

The case of non-domestic buildings is rather different. Many industries have been procuring buildings through a prefabrication route. Little, if any, social problem is associated with these being procured through prefabrication, and in many cases there is little public awareness that they are such (Phillipson, 2001).

The Human Settlements Review of 2010 (Chief Directorate: Gauteng Provincial Department of Local Government and Housing, 2010), presented another issue regarding the use of alternative building methods. Beneficiaries, i.e. the community, are not familiar with alternative technologies and innovative building systems. Communities have a perception that anything that is not built with bricks-and-mortar is substandard and unpleasant. Beneficiaries tend to believe that they are devalued by the state and are therefore given an inferior product (Chief Directorate: National Department of Human Settlements, 2010). This results in rejection, lack of buy-in and in some cases resistance at start-up of many projects.

Providers of alternative systems and technologies often do not - without government assistance - conduct sufficient marketing of their products to the beneficiaries (Chief

Directorate: National Department of Human Settlements, 2010). Lewis (2011), however, explained that the onus of marketing alternative building systems is on the Provincial Government, and not on the contractor. He goes on to suggest that this will most likely increase the costs of projects as the department has to invest in rigorous consumer education and intervention strategies.

This, however, is very much subject to the alternative in question. A material such as concrete is already widely accepted amongst most, if not all, communities. Therefore if precast concrete was used for the construction of a school, it does not necessarily require for the education of the community. A precast school will feel, look and perform similar, if not identical, to a conventionally built school and the common school learner would be, safe to say, none the wiser.

3.5 Socio-Economic (Labour)

The use of precast concrete components in building projects drastically reduces the amount of work on site (Polat, 2008). According to a study carried out by Tam (2002), there could be a 43% reduction in site labour consumption if there is a shift from the in-situ site casting to prefabrication design (Wong et al., s.a.). This factor might be an advantage in developed countries, where the cost of labour is far higher than in developing countries, but when viewed from a developing country's perspective, the use of prefabrication indirectly implicates job loss (Gerrie Willemse, 2011).

Table 3.2 depicts man-hours recorded on a 'hypothetical' project, in a research study done by Warszawski et al. (1984). The model chosen for the economic evaluation of precast alternatives was selected from the standard housing plans of the Israeli Ministry of Building. The model was a four-storey residential building with four identical 94m^2 apartments on each floor. The labour requirements were calculated from work quantities based on detailed designs for each alternative, and productivity measurements on-site and in prefabrication plants performed for this (Warszawski et al., 1984). The table depicts the labour hours required for the construction of the separate structural components, such as the walls, columns and floor slabs, for each construction alternative.

It can be seen that man-hours were found to decrease considerably as prefabrication usage increased. For a project using only conventional methods, the total man hours amounted to approximately 400 hours. On the contrary, when the same project was completed using only precast elements, the total man-hours almost quartered.

Activities group	**Labour Requirements, in Man-hours per Dwelling**					
	Conventional Method	Precast Floor Slabs		Non-bearing precast Walls	Precast slabs and bearing walls	
		Span 9.60m	Span 6.60m		Span 9.60m	Span 6.60m
Walls	163.8	153.6	153.6	61.1	43.4	43.4
Columns	67.3	55.7	65.4	76.4	-	9.7
Floor Slabs	173	75.3	50.8	173	75.8	51.3
Supporting Beams	-	59.1	75.3	-	-	16.2
Total	404.1	343.7	345.1	310.5	119.2	120.6

Table 3.2 - Labour Requirements of Different Construction Alternatives (Warszawski et al., 1984).

3.5.1 South African Context

South Africa is a developing country with an unemployment rate of about 24.9% (Statistics South Africa, 2012), therefore improvement of living conditions of the poor through job creation among others is, or should be, a priority of government. While conventional building processes have proven to have the ability to create a variety of opportunities for the unemployed in local communities through bricklaying, material provision, subcontracting of services, etc. alternative building technologies are not there yet. These technologies are often high tech, requiring extensive training and the use of specialist contractors (Chief Directorate: National Department of Human Settlements, 2010). At present, contractors employed by the Department of Transport and Public Works through traditional means are required to have 50% of their unskilled labour be members of the local community (Willemse, 2011).

On the other hand, employment for factory-produced buildings is easier as the factory site is permanent and skill shortages and numbers can be easily addressed. Local employment will always benefit (Taylor, s.a.). It goes without saying that a person employed in a factory environment will have enhanced job security than someone on a project with a start and end date. In addition, they will learn a skill and hence transcend from unskilled to skilled.

The need to bring benefits to a larger audience (e.g. create work and supply opportunities for local labour, consultants, contractors and suppliers; provide training to upgrade local skills; develop domestic capability to compete in other market places) can introduce additional costs to the client and developer. Broader socio-economic objectives can lessen the opportunities for innovation by limiting the participation of foreign parties who possess specialized knowledge and expertise that may not exist locally (Russell et al., 2006).

However, the use of local resources and knowledge can sometimes speed up the construction delivery process and increase the predictability of costs and construction activities in labour intensive production processes. Local knowledge and experience can often lead to a more effective control and sourcing of construction materials and equipment. Requirements for broader socio-economic benefits, often incorporated into contracts and concession agreements through compliance clauses, can act as a driver or inhibitor of innovation, depending on the type of innovation in question: product innovations may be constrained, but stability and predictability in local labour, material, and equipment supply may bring forth efficiencies in the construction phase, leading to some process innovations (Russell et al., 2006).

The construction industry in South Africa is one where skilled labour is in short supply but unskilled labour is abundant. At the same time, manufacturing processes are becoming more efficient and cost effective (Murtaza et al., 1993). Therefore, the industrialised building methods such as preassembly, prefabrication and modularisation are expected to be major options in the choice of future construction methods and labour relationships need to be developed in parallel. This would require a strategy whereby the advantages of employing local labour are combined with the inherent characteristics of precast construction as previously mentioned. One such example could be where 'satellite' factories are erected at the various project locations and which then employ local labour. This in turn, can make the community feel as if they are a part of the solution and as such create a sense of community (Angelucci, 2012). This proposal however is discussed in more detail in **Chapter 6**.

3.6 Logistics

The growth market for prefabrication has fuelled a broad spectrum of innovative ideas in design and engineering. In parallel with these developments the logistics of transferring the completed item from the factory to the site and the final installation in the building have become more complex (Gibb, 1999). Expert advice on transportation and installation should always be sought at the earliest opportunity.

The scope of prefabrication is limited by an organisation's ability to transport large components to local or remote locations and the size of the transportation available (Boyd et al., 2012). Although some transport of building products may occur by rail today, prefabricated elements in almost all circumstances arrive onsite by truck. The rare exceptions are sites located directly adjacent to rail lines or seaports in which building components may be loaded and unloaded directly to the location of assembly (Smith, 2010).

In making decisions with regard to prefabrication, transportation costs need to be calculated as a part of the cost estimate. The size, weight, transportation method and distance of travel determine transportation costs. The transportation cost of precast components from the plant to the site is directly proportional to the transportation distance (Arditi et al., 2000). Often a radius is determined by manufacturers, calculating the maximum distance to another similar manufacturer, or simply the limits of their capacity to deliver (Smith, 2010).

Seaker and Lee (2006) argue in a report titled "Assessing Alternative Prefabrication Methods: Logistical Influences" that among logistical concerns such as material carrying costs from acquisition to install, transportation is the operation attributed to the highest cost increase over on-site operations.

Notable in this report is the distance at which off-site units become cost prohibitive – around 200 to 300 kilometres from the factory. This distance is consistent with numbers established from both American engineering firm 'Buro Happold' and research performed by the American housing company 'Pulte'. Buro Happold state that for most projects 200 kilometres is the limit of cost-efficient transport (Smith, 2010). Likewise Pulte Homes, found their system is limited to 200 kilometres from the plant (Sawyer, 2005). This number continues to emerge as a standard in the building industry from factory to site. Logistically, it is not cost beneficial to ship from further distances unless a large margin is made up in labour, time or material costs (Smith, 2010).

The situation in South Africa is similar. Various South African precast concrete manufacturers were contacted and short telephonic conversations were held by the author and the person in charge of transportation for each individual company. Rough numbers obtained from the respective companies, puts 200 kilometres as the average distance where transport remains feasible **(Table 3.3)** or where another manufacturing plant is deemed closer.

Some manufacturers claimed that although costs do increase as distance increases, it is nonetheless the clients' choice, and more so the projects' location and characteristics of the surrounding vicinity, that dictate to what extent transport remains a factor. For example, a project in a rural location where skilled labour and raw material required for in-situ is poorly available, lends no other option than to use precast factory produced components and transport cost hence becomes irrelevant.

Precast Manufacturer	Plant Location	Radius (km)
Cape Concrete©	Blackheath, Western Cape	100
ROCLA©	Blackheath, Western Cape	200
Elematic SA©	Benoni, Gauteng	No Limit
Cobute©	Kilarney, Western Cape	200
Corestruc©	Polokwane, Limpopo	250
Shukuma Flooring Systems©	Port Elizabeth, Eastern Cape	350
Top-Floor©	Belville, Western Cape	150
Concrete Units©	Cape Town	200
Neat Contech©	Humansdorp, Eastern Cape	200
Bobcrete©	Belville, Western Cape	200
		205

Table 3.3 - Plant location and 'ideal' transport distance of various South African precast manufactures.

Another constraint related to transportation of prefabricated units is the allowable weights and dimensions of loads specified by the respective highway agencies. The project has to be handled in such a way that the component sizes do not exceed the weight/size limitations specified by highway agencies (Arditi et al., 2000).

The weight/size limitations specified by highway agencies might constrain designers' creativity by compelling them to keep the component sizes within limits when designing precast concrete structures (Polat, 2008). Therefore, because of these limits imposed on the designer's ambitions, the size and weight of the completed units need careful consideration at the design stage (Gibb, 1999).

3.6.1 South African Context

The National Road Traffic Act (Act 93 of 1996) and the National Road Traffic Regulations, 2000 prescribe certain limitations on vehicle dimensions and axle and vehicle masses that a vehicle using a public road must comply with (Committee of Transport Officials (COTO), 2010). However, certain vehicles and loads cannot be moved on public roads without exceeding the limitations in terms of the dimensions and/or mass as prescribed. Where such a vehicle or load cannot be dismantled, without disproportionate effort, expense or risk of damage, into units that can travel or be transported legally, it is classified as an abnormal load and is allowed to travel on public roads under an exemption permit issued in terms of Section 81 of the National Road Traffic Act (Republic of South Africa, 2008).

The length of a precast element for a commercial development is rarely restrictive as units seldom if ever exceed 12 metres, which is a 'normal' vehicle length (Gibb, 1999). Hollow-core slabs, for example, are available in spans of up to 11 metres and in widths not exceeding 1.2 metres (Concrete Manufacturers Association, 2008). However, combinations of length, height and width need to be considered. Transport weight is also not normally a limiting factor as unit weights rarely exceed the permitted loadings on normal roads.

Table 3.4 below contains a summary of legal limits on the size of road vehicles imposed by the National Road Traffic Act of South Africa.

	Overall Dimension (m)
Length: • Single Vehicle • Articulated Vehicle • Other combinations of vehicles	 12,5 18,5 22,0
Width: • Goods Vehicle ≥12 000kg • Other vehicles	 2,6 2,5
Height: • Any road vehicle	 4,3

Table 3.4 - Dimension Limitations of Road Vehicles (Republic of South Africa, 2008).

The maximum permissible weight of a vehicle, however, is not limited to a fixed numerical value, but instead depends on (Committee of Transport Officials (COTO), 2010):

- the capacity of the vehicle as rated by the manufacturer,
- the load which may be carried by the tyres,
- the damaging effect on road pavements,
- the structural capacity of bridges and culverts,
- the power of the prime mover(s),
- the load imposed on the driving axles, and
- the load imposed on the steering axles.

The above apply provided the permissible maximum combination mass of any combination of the above does not exceed 56 000 kilograms (Republic of South Africa, 2008). It can hence clearly be deduced that any current or future precast element which will be used for school construction is unlikely to exceed these limitations. The only exception could be where complete class room modules or parts thereof are prefabricated **(Figure 2.2).** In such cases, these would require special transportation arrangements and would need to be preferentially fabricated on-site or very close.

3.7 Health & Safety

Construction sites in general are hazardous environments. On-site construction conditions often require workers to potentially be exposed to harsh weather conditions and precarious positions near roads, hazardous protrusions, and the like (Smith, 2010). In a report by the Health and Safety Executive (HSE, 2011) on workplace fatalities and injuries in Great Britain, fatal accidents were found to be up to twice more likely than in the manufacturing sector. The data from this report is depicted in **Figure 3.1**.

One can argue that the gradual decrease in fatalities could be linked to the improvement in the efficiency of the UK construction industry, due in part to the Latham (1994) and Egan (1998) reports. These reports called for methods of improving the construction industry as a whole, and coincidently recommended the increased use of prefabrication as a solution.

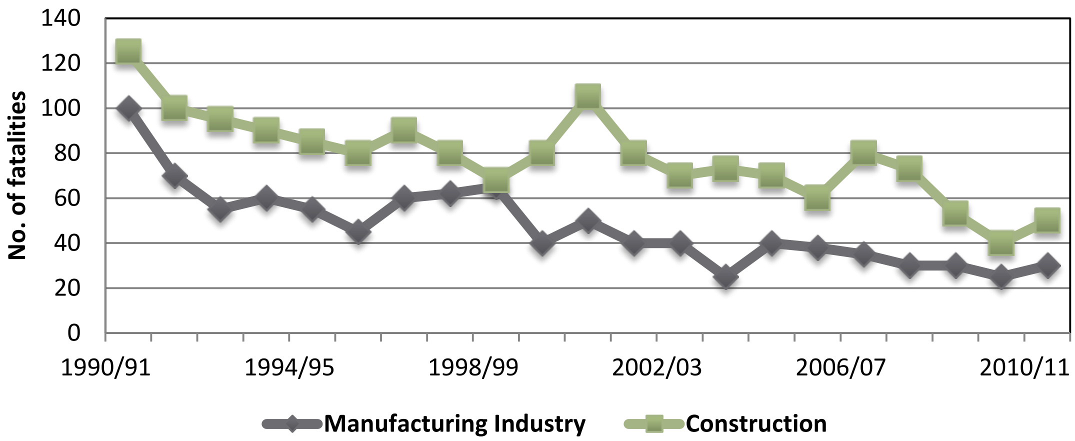

Figure 3.1 - Twenty Year Trend in Worker Fatalities (HSE, 2011).

In a similar report by the CIDB entitled "Construction Health & Safety in South Africa" (CIDB, 2009), detailed analysis of the Federated Employers' Mutual Assurance Company's (FEMA) statistics of claims received showed that:

- The dominating causes of injuries were 'struck by' (44%), 'falls on to different levels' (14%) and 'striking against' (10%);
- The dominating causes of fatalities were 'struck by' (17%) and 'falls on to different levels' (17%).

Relating these to the UK figures, it shows that almost 1 in every 5 claims received from fatalities are in the construction sector. Both the UK and South African statistics indicate that the construction environment is hazardous in nature and injuries are more common than in other industries.

Enhanced occupational health and safety is therefore something that is desired and this is one of the advantages prefabricated systems offer (Polat, 2008). Prefabrication reduces the amount of work that is done on-site and therefore reduces exposure to hazards (Gibb, 1999). Transferring much of the construction programme from an open site to a controlled factory environment reduces on-site time for workers and reduces the potential for site-based accidents and ill health (Taylor, s.a.). The conditioned, dry interior environment of the factory enables responsible manufacturers to make appropriate provision for the health and safety of their workforce. The responsibility of site construction employers is just as great, but their task is more demanding because under site conditions it is far harder to eliminate the hazards or control the risks (Gibb, 1999). The relatively low-scale nature of both on-site and off-site works leads to significantly reduced risks attached to working at heights and encourages a safety ethic (Boyd et al., 2012).

Furthermore, prefabrication tends towards a more thought-through approach to construction management, in that its deliveries and installations need to be planned in advance in order for them to work at all. The increased planning involved in prefabrication provides opportunity for appropriate risk assessments to be completed (Gibb, 1999).

Prefabricated units also usually require craneage installation which needs careful consideration for health and safety, but need not increase the risks (Gibb, 1999).

3.7.1 South African Context

In South Africa the need to provide safe working environments for labourers is extremely important since most construction methods in South Africa at present are very labour intensive. The Occupational Health and Safety Act 85 of 1993 stipulate specific responsibilities towards members of the project team to ensure a safe working environment (Government of South Africa, 1993).

The Construction Regulations of 2003 is an additional safety regulation that is subjected to the Occupational Health and Safety Act 85 of 1993 and is drafted specifically for the construction industry (Government of South Africa, 1993). Some of the precast concrete aspects affected by these regulations are crane and hoisting operations, waste removal and scaffolding.

Furthermore, the Construction Industry Development Board (CIDB) Act no. 38 of 2000 mandates the CIDB to determine and establish best practice standards that promote positive safety, health and environmental outcomes. This Act mandates the CIDB to create a Best Practice Project Assessment Scheme based on the mentioned standards. According to the scheme, contractors that undertake contracts above a prescribed tender value are assessed according to their compliance with the best practice standards and guidelines (CIDB, 2009).

As mentioned before, prefabrication tends towards a more thought-through approach to construction management. The increased planning involved in prefabrication provides opportunity for appropriate risk assessments to be completed beforehand and it can therefore be verified whether all of the above regulations are adhered to.

3.8 Procurement Strategy

Prefabrication is widely promoted as a means of improving construction performance and transforming it into a modern, safe and efficient industry (Blismas et al., 2005). However, implementation of prefabrication has been slow and erratic in most countries (especially developing ones) due in part to process and procurement constraints inherent within most construction projects. Moving towards greater degrees of prefabrication, flexibility in the project process progressively diminishes (Smith, 2010).

In order to maximise the benefit from prefabrication it is essential that a project-wide strategy be developed at an early stage in the project. Prefabrication must be considered from an overall project perspective rather than an individual element view, so as not to lose the strategic benefits from having an overall strategy (Gibb, 1999). At the beginning of a project, architects and clients must consider approaches to procurement. Design and building teams must work together – architects, engineers, contractors and subcontractors working to find an appropriate project-wide strategy to prefabrication (Smith, 2010).

Figure 3.2 describes how the prefabrication strategy should be applied to maximise benefit to project outcomes throughout the project life-cycle and demonstrates that although benefits can still be obtained from decisions made at a later stage, their effect on the overall project will be much more limited.

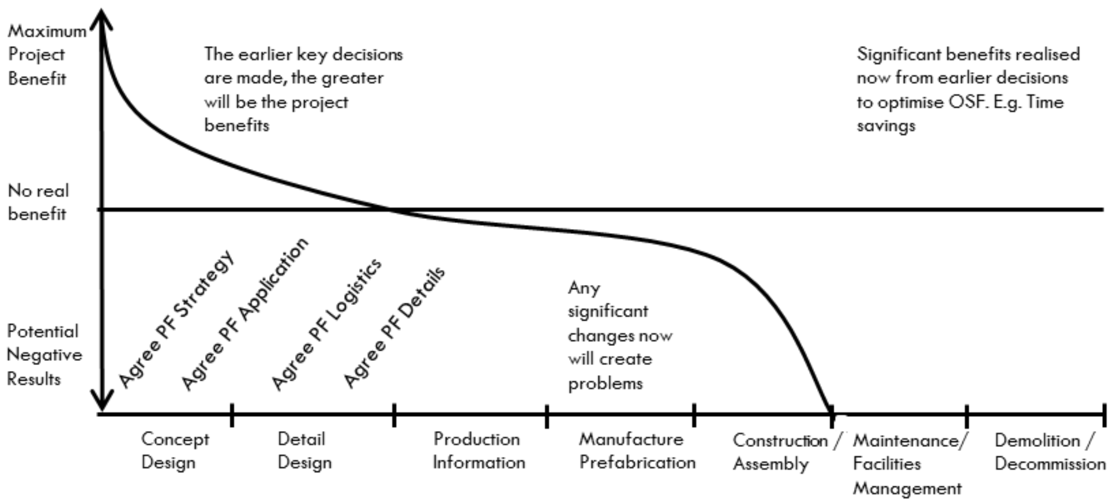

Figure 3.2 - Timing of Prefabrication decisions to maximise project benefits (PF = Prefabrication, OSF = Off-site fabrication) (Gibb, 1999).

The delivery method selected by the client can have a large impact on the determination and extent of prefabrication (Smith, 2010). Although prefabrication can be used in any contract structure, certain kinds of contracts are more suited to off-site construction than others (Kullman Buildings Corp., 2008) and certain procurement methods can facilitate early manufacturing input (Gibb, 1999). These are discussed in more detail in the next chapter.

3.9 Conclusion

Prefabrication was shown throughout this chapter to contain numerous advantages which directly address amongst others the construction principles of time, cost and quality. It is presented that savings in time directly lead to savings in budget. Some hidden costs associated with prefabrication were looked at as well, so as to maintain an objective stance. It was determined that although prefabrication might not be cheaper initially, the other advantages it presents outweigh the higher initial expenditure. Quality was additionally found to increase due to the controlled environment of a factory. All the same, prefabrication was found to be inherently beneficial with regards to time, cost and quality.

Labour was found to be a sensitive issue due to the inherent nature of the South African political and economic situation. Where a decrease in labourers on site would be viewed as an advantage in most developed countries, it is seen as a disadvantage in South Africa. This is a major barrier to innovation and further research is required in this regard. However, prefabrication did show to provide more job security due to the nature of a factory environment. In addition, a faster rate of construction will also counter the effect of a reduction in site labour.

Logistics do not pose a problem as most precast elements applicable to the construction of schools do not exceed limitations set by the highway regulatory bodies in South Africa. One issue, however, arose in the distance of projects from the factory/assembly site. An optimal cost-efficient distance was determined for prefabricated units before it becomes cost-prohibitive, but this figure of approximately 200 km was seen to be open to dispute. It was found that the nature of the project dictated the travel distance. A project in a rural area where resources are scant, in effect negates the restraints on feasible travel distances as there is no alternative to getting the components to the site location. In goes without saying though, that on-site fabrication, such as tilt-up construction, will eliminate to a large extent the logistical concerns.

Prefabrication was also found to have considerable occupational health and safety benefits, due mostly to the reduced number of personnel on-site and the controlled environment of the factory. Also, due to the increased preliminary planning associated with prefabrication, a more thought through approach and comprehensive plan can be given to health and safety. It does, however, remain a construction method which requires a skilled and experienced contractor. Insufficient training in the setting and placing of the components can be hazardous, and therefore a well-trained and alert team, and a well-founded health and safety plan is required for it to be implemented optimally and safely.

Supplementary to the initial hypothesis, prefabrication appears to be an advantageous approach and since the term 'prefabrication' was determined by the preceding chapter to be akin to 'Precast Modular Construction', it can be deduced that Precast Modular Construction at this point proves to be a credible alternative to traditional construction methods, but also provides many time, cost, quality, socio-economic, and health and safety benefits.

Some concerns do, however, present potential barriers, such as the decrease in labour on-site, the shortage of specialised skilled labour and the transport distances to the rural areas where the schools are required. Some potential solutions to these issues were discussed, but gradually during the next chapters, a proposal is created to address these concerns and further cement the plausibility of the initial hypothesis.

Lastly, the implementation of prefabrication was found to warrant a project-wide strategy which requires procurement systems specifically suited to the prefabrication design considered. The succeeding chapter considers the various contract strategies available, which ones are currently implemented, and those most suited to the use of prefabrication techniques. Eventually a procurement strategy fitting to both prefabrication and school construction is established.

Chapter 4

Procurement Systems

4.1 Introduction

Choosing the right procurement system is essential for the success of any procurement project and is almost as important as choosing the right procurement team. Smith et al (2004) describe it as the 'single most important decision that the client makes other than the decision to build.' This is so because the type of procurement system chosen should be adequate enough to address the particular needs of the client. Moreover, the benefits of any particular method will not be gained if it is wrongly applied and the constraints will be magnified if used to procure the wrong type of project.

This chapter seeks to determine what is available in terms of procurement systems. The differences between them are defined along with the circumstances in which each is best suited.

The latter part of the chapter is concerned with defining the process behind selecting a procurement strategy, and furthermore how this changes when viewed from a prefabrication and school construction perspective. Opinions from various literature sources are considered, and eventually a conclusion is drawn on which approach is best suited to the precast modular construction of schools.

4.2 Definition of Procurement

The procurement concept in construction has been defined in many ways. *The Oxford English Dictionary* offers a general definition of the term procurement as: 'The action or an act of causing, arranging, or bringing about, especially through an agent'.

More sophisticated definitions have been attempted and given as – 'the acquisition of new buildings, or space within buildings, either by directly buying, renting or leasing from the open market or by designing and building the facility to meet a specific need'. For purposes of a debate held at the Montreal Symposium in 1997 (McDermott, 1999), the following definition was accepted: 'Procurement is a strategy to satisfy client's development and/or operational needs with respect to the provision of constructed facilities for a discrete life-cycle'. This sought to emphasize that the procurement strategy must cover all of the processes in which the client has an interest, perhaps the whole lifespan of the building (McDermott, 1999).

However, it has been argued that for some research purposes the usefulness of definitions such as this is limited to developed market economies, supported by the notion of the inadequacy of the common classification criteria for procurement systems (that is traditional, design-build, etc.) in enabling global comparisons. However, a working definition of procurement was developed by the CIB W92 at its meeting in 1991, defining it as 'the framework within which construction is brought about, acquired or obtained'. This definition served a useful purpose as it is both broad, encouraging a strategic interpretation, and neutral, being applicable not only to developed, market economies (McDermott, 1999).

4.3 Procurement Systems in Construction

One of the problems that have beset this particular area of construction research is a lack of clear definitions as to what is meant by procurement systems or terms such as contract strategy, or even the meaning of design-build (Rowlinson, 1999a). No standard definitions and classification of procurement approaches have become generally acceptable, quite simply because there are no formal structures or agreement on the terms. The term 'procurement system' implies a degree of scientific rigour which does not exist. McDermott, (1999) argues that either the term 'procurement path' or 'procurement approach' would be preferable. Hence, the definitions used in this thesis are briefly discussed below.

The first issue is to distinguish clearly what is meant by construction. In this thesis we are looking at the complete life cycle of the whole project process, from design, to construction process and through to its realisation and use. The design encompasses the whole range of planning, funding, structural and architectural design and documentation. All those activities required to be able to break ground on a new site. The construction process is seen as involving all those activities, be they technical, managerial or strategic, which make up the realisation phase of the project where the physical facility actually appears (Rowlinson, 1999a).

The type of construction referred to is types of projects in the engineering and construction works, more specifically the construction of school buildings.

4.3.1 Definition in the South African Context

The SANS 294:2004 defines procurement as a process (i.e. a succession of logically related actions occurring or performed in a definite manner) which culminates in the completion of a contract for the provision of engineering and construction works, supplies, services or disposals. There is a finite range of methods and procedures associated with the various procurement sub processes.

This standard describes the generic processes around which an organization can develop its procurement system. It also describes standard methods and procedures which can, by reference, be adopted by organizations into their procurement systems. The processes, methods and procedures contained in this standard are based on the underlying requirement for the procurement system to be fair, equitable, transparent, competitive and cost-effective. How this affects the choice in procurement approach, is discussed at a later stage.

4.4 Contract Strategy

Procurement is about the acquisition of project resources for the realisation of a constructed facility. This is illustrated conceptually in **Figure 4.1**. The figure clearly shows the construction project as the focal point where the whole series of resources combine.

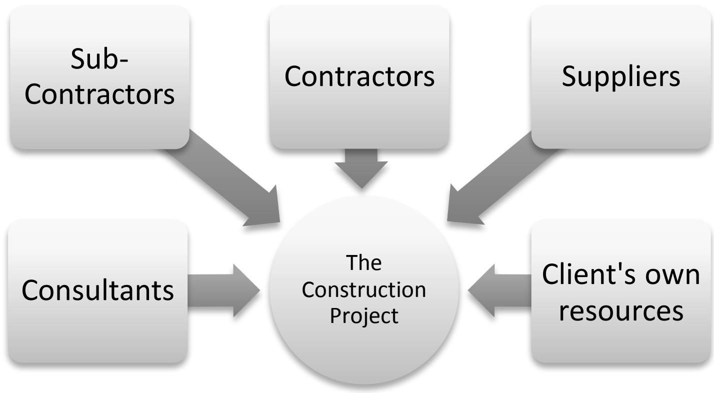

Figure 4.1 – Procurement (Rowlinson, 1999a)

Central to this model is the client's own resources that are supplemented by the construction industry participants, that is, the consultants and the contractors along with the suppliers and subcontractors. This model clearly illustrates the need for the acquisition of resources in order to realise the project. This acquisition of resources is part of the procurement system – emphasis being on it being only a part of the system. This part of the system can be referred to as the *contract strategy*, that is, the process of combining these necessary resources together. The contract strategy is not the procurement system but only a part of it: the rationale behind this definition is that the procurement system involves other features such as culture, management, economies, environment and political issues (Rowlinson, 1999a).

4.4.1 Contract Strategies in South Africa

Table 4.1 provides the range of commonly used contracting strategies for engineering and construction works contracts in South Africa as compiled by the Construction Industry Development Board (CIDB, 2005).

Design-Bid-Build (Traditional)	The Contractor undertakes only construction on the basis of full designs issued by the Employer
Design-build	The Contractor undertakes most of the design and all construction in accordance with the Employer's brief and his detailed tender submission, usually for a lump sum price.
Develop and Construct	Similar to design-build, except that the Employer issues a concept design on which tenders are based.
Management Contract	A management contractor is appointed to engage and manage a number of trade contractors to carry out construction on the basis of designs issued by the Employer, as and when they are completed. The trade contracts are between the management contractor and the various trade contractors.
Construction Management	Similar to a management contract, the main difference being that the trade contracts are between the Employer and the various trade contractors/consultants.

Table 4.1 - Range of commonly used contract strategies in South Africa (Marx, 2012).

The distribution of contracting strategies by different employer categories is shown in **Table 4.2**. This table was compiled as a result of the 2011 survey of the CIDB, and contains feedback from 592 employers of completed projects. It is evident that the design-bid-build (traditional) was the most popular for all employer categories. However, it is promising to note that the provincial departments also used the design-build strategy for 29% of their projects (Marx, 2012).

Contracting Strategy	% Projects with Contracting Strategy per Employer Category					
Design-Bid Build	68	79	71	57	83	84
Develop-Construct	5	5	-	4	4	-
Design-Build	11	8	3	29	4	12
Management Contract	10	4	13	2	2	4
Construction Management	6	4	13	8	7	-
Employer Category	**Private Sector**	**Public Corporation**	**National Department**	**Provincial Department**	**Metropolitan Council**	**Regional/ District Council**

Table 4.2 - Contracting strategies adopted per employer category (Marx, 2012).

As one moves from design-bid-build to design-build, an increasing integration of design and construction results within one organisation. Masterman (1985) further classifies the above strategies into three major categories:

- **Separated and Co-Operative Systems**
  - Design-bid-build/Traditional/Design by employer
- **Integrated Procurement Systems**
  - Design & Build, Develop & Construct
- **Management-Orientated Systems**
  - Management Contract, Construction Management

Following this paragraph, is a generic categorisation of organisational forms so as to provide a clear and simple description of construction project organisational forms which, when taken with other contract strategy variables, uniquely define a strategy which is further clarified when put in the context of the overall procurement system (Rowlinson, 1999a).

4.4.1.1 Separated and Co-Operative Contract Strategies

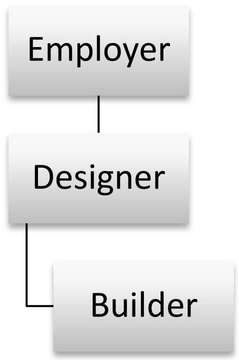

Figure 4.2 - Separated Procurement Systems (El Wardani, 2006)

The system of traditional tendering is based on the rigid separation of the design and construction activities **(Figure 4.2).** The client appoints a team of consultants, usually following the feasibility study, in order to develop the detailed design. The design team prepares all drawings, specifications and bills of quantities, before the process of tendering for the selection of a suitable contractor takes place. Contract award is usually on the basis of lowest bid-price, although some of the more enlightened clients are now starting to consider a range of criteria, weighted in accordance with the potential impact on successful project outcome. The appointed contractor is responsible for the execution of all construction works, which may be undertaken using a combination of subcontractors and direct labour (Cox & Townsend, 1998).

The main idea here is that actual construction only begins after design has been completed and furthermore, it is usually handled by a different firm to the one that does the design. The following variances of the traditional method were also identified by Masterman (1985):

- Two-stage selective tendering
- Negotiation
- Continuity contracts
- Serial contracts
- Cost reimbursable contracts.

The following list summarises typical circumstances in which separated contracts are used (Murdoch & Hughes, 2008):

- The employer has instructed the design to be prepared and for the purposes of the building contract takes responsibility for it.
- The employer's designer is sufficiently experienced to co-ordinate and lead the design team and to manage the interface between design and production.
- The design is substantially complete when the contractor is selected.
- An independent quantity surveyor will be used to plan and control the financial aspects of the project.
- The contractor is selected on the basis of the contractor's estimate and carries the risk that the estimate may be wrong.
- The employer reserves the right to select sub-contractors for certain parts of the work.
- The employer makes no explicit preference to a specific strategy and the advisors do not raise the issue of choosing one.

4.4.1.1.1 South African Context

In a personal interview conducted with Willemse (2011), who holds the position of Chief Engineer at the Department of Transport and Public Works (DTPW) in the Western Cape, he stated that the process described above was the current method employed by most, if not all, school construction projects in South Africa. The selection of *consultants* is done on a point's basis, whereby consultants state their availability by being listed on the departmental 'roster'. By being listed, the firm makes known its capabilities, specialities and company structure. The DTPW then evaluates the firm according to certain criteria, and awards the project to the firm with the most points. He also mentioned that they are considering a tender system for the appointment of consultants.

Contractors, however, are not chosen on a 'roster' basis but on a competitive tender basis. An 'in-house' bill-of-quantities is compiled to put the received tenders into perspective. The contractors also need to be CIDB registered.

4.4.1.2. Integrated Procurement Systems

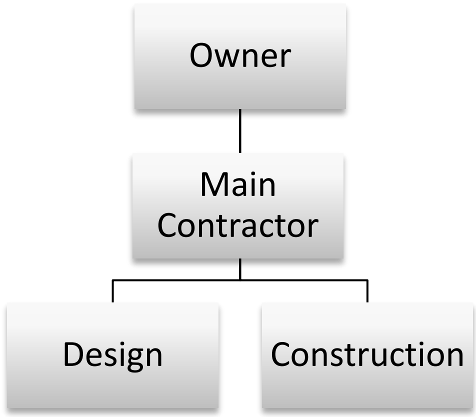

Figure 4.3 - Integrated procurement methods (Chan & Yu, 2005)

Commonly referred to as design-build, integrated procurement methods approach is defined as a project procurement method where one entity or consortium is contractually responsible for both design and construction (Lam et al., 2004). This system simply means that the contractor offers to undertake the entire design and construction of a project for the client **(Figure 4.3)**. Although the contractor assumes the overall responsibility for project delivery, the client may appoint an independent advisor to monitor quality and cost. There is nothing particularly new about this concept and has been widely employed in countries such as Japan and the United States, and at a later stage in the UK (Cox & Townsend, 1998).

Variants on the design-build theme exist, one such being develop and construct, where the design is partially completed by the employer's designers, before contractors are asked to complete and guarantee the design in a competitive tender.

Cox & Townsend (1998) state that either competition or negotiation methods may be used in the selection of a design-build firm, depending on the amount of up-front information. There also obviously needs to be sufficient detail to allow a meaningful competition. Clients may also require professional assistance to prepare the brief, and monitor progress during the project.

This approach is favoured in the following circumstances (Toler, 2007):

- For projects that are not sensitive to aesthetic issues and in which engineering concerns dominate over architectural ones, such as industrial plants.
- Project complexity with high risk in separating design and construction responsibility (power-generating facilities, paper plants, nuclear power plants, chemical processing plants and refineries, water and waste-water treatment plants).
- Where owner's requirements can be clearly stated.
- Particularly attractive where owner's requirements can be defined by objective performance criteria that are readily understood by the industry.
- Where owner's requirements are largely prescribed by industry or regulatory standards (civil infrastructure projects such as roads and bridges).
- Where owner is a sophisticated organization experienced in design-build.

4.4.1.3 Management-Orientated Procurement Systems

A variety of management systems were developed in the UK, during the late 1960's, in response to the limitations of traditional systems on increasingly complex projects. The common feature is that a client enters into a contract with an external management organisation, which is responsible for the management and co-ordination of design and construction of the proposed works. There are several variants on this theme of which the most commonly used are management contracting and construction management.

4.4.1.3.1 Management Contracting

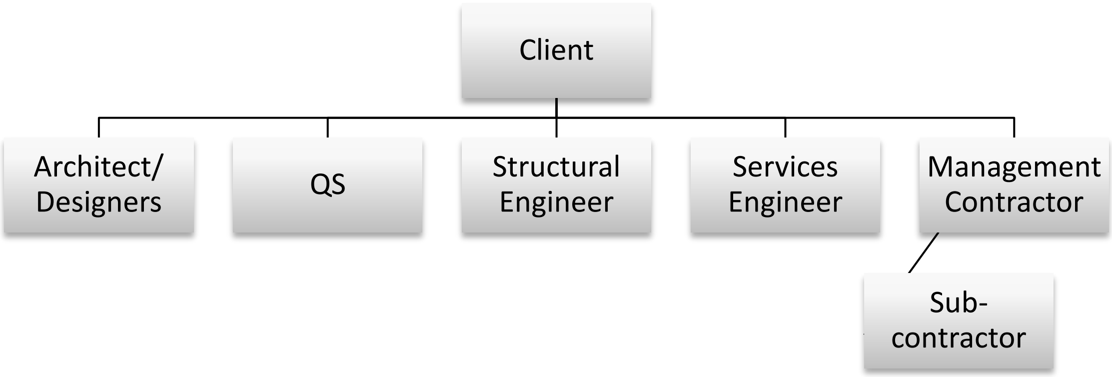

Figure 4.4 - Management Contracting (Murdoch & Hughes, 2008)

Also sometimes referred to as the 'construction-management-at-risk' method, management contracting is a delivery method where the appointed general contractor does not normally undertake any of the permanent construction works, but provides management services to control and co-ordinate all site activities, sub-letting the actual works to suitable contractors on a competitive basis (Cox & Townsend, 1998). In effect, management contracting is a procurement method consisting of 100% sub-contracting **(Figure 4.4)**. This sub-contracting feature is what distinguishes management contracting from the construction management approach (Murdoch & Hughes, 2008).

This approach is favoured in the following circumstances (Murdoch & Hughes, 2008):

- The employer wishes the design to be carried out by an independent architect and design team.
- There is a need for early completion.
- The project is fairly large.
- The project requirements are complex.
- The project entails, or might entail, changing the employer's requirements during the building period.
- The employer, while requiring completion, wants the maximum possible competition in respect of the price for the building works.

4.4.1.3.2 Construction Management

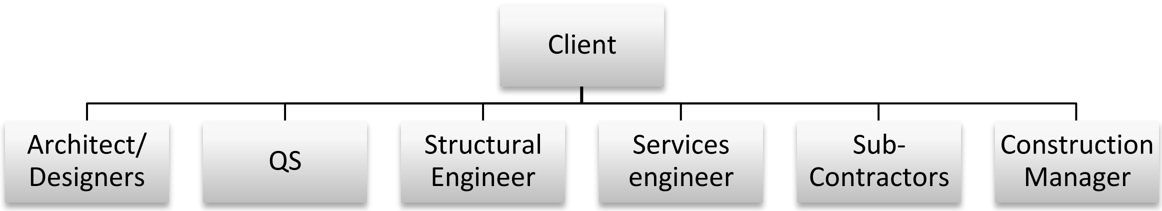

Figure 4.5 - Construction Management (Murdoch & Hughes, 2008)

This approach primarily evolved in response to a major shortcoming in the system of management contracting. Adversarial attitudes had re-emerged on some contracts, due to client tendencies towards assigning increasing levels of risk to management contractors, which they could neither manage nor reasonably price. This led to the management contractors effectively being responsible for the default of sub-contractors, without having the authority or flexibility to manage the whole design and construction process.

Using construction management the client enters into separate contracts with a designer, a construction manager and various sub-contractors (Cox & Townsend, 1998) **(Figure 4.5)**. This technique overcomes many of the problems of the management contracting method, because there is no direct contractual link between the construction manager and the trade contractors (Murdoch & Hughes, 2008). Developed in the United States, this approach allows clients to build quickly and play a part in the total process.

Construction management recognises the role of management as an explicit professional function, separate from contracting.

This approach is favoured in the following circumstances, which are somewhat similar to those favouring the use of management contracts (Murdoch & Hughes, 2008):

- The client is familiar with construction, and knows some or all of the professional team.
- A private sector employer requiring a commercial building.
- The project is technologically complex involving diverse technologies and-subsystems.

- The employer wants to make minor variations to requirements as the project proceeds.
- There is scope for separating responsibility for design from responsibility for management of the project.
- The employer requires an early start on site.

4.4.2 Contract Strategy Variables

It is beyond the scope of this thesis to go into excessive detail on the various methods of project delivery, but as mentioned before, uniquely defining a contract strategy merely by its organisational form (traditional, design-build, etc.) is imprecise. Therefore an overview is given below of some of the variables mentioned by Rowlinson (1999a) which, together with the organisational form, define a project delivery method more clearly.

- **Payment methods** – Either lump sum, or cost plus. The design-bid-build and the design-build methods may be more suitable under a lump-sum contract, while the management contracts are generally the preferred method for cost-plus contracts (Al Khalil, 2002).
- **Overlap of project phases** – This variable defines the degree of acceleration or fast-tracking that is desired within the construction process. Traditional processes are difficult to fast-track and overlap because of the serial sequencing of phases, but varying degrees of overlap can occur with both the design-build and separated contract approaches (Al Khalil, 2002).
- **Selection process** – Contractors may be selected by open competition, by selecting competition among an unlimited number of prequalified contractors or by negotiation in one or more stages. Similar methods may be adopted for the selection of consultants. However, any of these processes can be used with any of the organisational forms but conventionally set patterns have been implemented, with the traditional system adopting open or selected competition and design-build moving towards select competition or negotiation in the selection process.
- **Source of project finance** – If the employer provides finance then they essentially have a free hand in the choice of strategy, but if 3rd parties or the contractor organisation provide part or all of the finance, then the situation becomes more

complex. In the context of school construction, the Department of Public Works can be viewed as the employer and as with any governmental endeavour, has to provide its own funding - in this case, public funds.

- **Contract Documents** – The appropriateness of the documents to the type of contract strategy being used is important. The contract document should match the strategy and procurement system adopted. South Africa at present mainly use the *General Conditions of Contract* (GCC) and *Joint Building Contracts Committee* (JBCC) documentation for most civil and non-residential projects (Marx, 2012).
- **Leadership** – In the past, in the traditional system, the role of the leader went to the architect by default. If a contingency view of contract strategy is adopted then this choice by default must be questioned and the leader fitted to the strategy adopted.
- **Authority and Responsibility** – The distribution of authority and responsibility are important issues in any organisation and the design of the distribution of these is paramount in project organisations. Distinctions have to be made in design and management responsibility (Murdoch & Hughes, 2008).

Al Khalil (2002) identifies further variables which affect the contract strategy:

- **Project characteristics**
  - **Clarity of scope**

    The clarity of the project scope and requirements of the owner can affect the decision to select a project delivery method. Generally a design-build approach requires a well-defined scope where the project requirements can be determined early in the design process. Other methods are more appropriate if the scope is vague and its definition is evolving.
  - **Complexity**

    Whether a project is a standard, repetitive design or a complex unique design is also a factor in selecting a preferred project delivery method. Generally a design-build is suitable for a standard design. In the case of a complex design, design-bid-build may be used.

- **Owner's preferences**
    - **Responsibility**

      Some owners may prefer the characteristic of design-build contracts of a single point responsibility. In a design-build system, the contractor is responsible for both design and construction errors. However, in such a situation there may be a tendency to cover some of the errors. Hence, other owners may prefer other types of systems which provide for checks and balances between design and construction (Al Khalil, 2002).
    - **Design control**

      Owners must determine how much they want to be involved with the design process to influence the final outcome of the design. A high level of involvement may be necessary if the owner wishes to generate a creative design or a special appearance which he has in mind. In such a case, a traditional or a management approach would be more appropriate. The owner may have limited control of detailed design under a design-build approach.
    - **Owner's involvement after award of contract**

      Owners must determine how much involvement they can afford to offer during the execution of the project.

Now that all the types of contract strategies and the affecting variables have been discussed, the processes behind choosing an appropriate approach are explored.

4.5 Choosing a Procurement System

Section **4.4** highlights the most suitable circumstances for each of the procurement methods but in no manner proposed a typical way of arriving at a conclusion to use any specific method. It was merely a discussion on situations in which the methods are optimally implemented. Choosing an appropriate project delivery method is essentially a much more complex process, as each project has its own characteristics and requirements, and for the project to be successful, the procurement method must address the technical features of the project alongside the client and contractor needs (Alhazmi & McCaffer, 2000).

Many attempts have been made to produce sophisticated systems for contract strategy selection (Rowlinson, 1999b). Whilst having some usefulness as a first guess at which contract strategy could be adopted, the fact remains that these systems take into account only a limited set of criteria in developing a solution to any procurement problem. For example, systems are very much country-dependant and are also dependant on the particular time at which they are developed – what is acceptable in terms of criteria and performance in Australia in 2009 may be totally irrelevant to South Africa in 2011 (Rowlinson, 1999b). What is needed is a set of issues that need to be addressed, rather than criteria.

There are key determinants, chosen at the outset of a project (by positive choice or default) which determines the structure within which the project will take place. These were discussed in **4.4.2** and include:

- Organisational form
- Payment method
- Overlap of project phases
- Contractor selection process
- Source of project finance
- Contract documents
- Leadership
- Authority and responsibility
- Project scope and complexity
- Owner's preferences

To further complicate matters, all of the above factors operate within the project environment, which is affected both by macro and micro factors, such as (Rowlinson, 1999b):

- Political environment
- Economic environment
- Environmental issues
- Socio-technical system (culture)
- Organisational system

Furthermore, the methods of selection open to the private client may be a matter of choice or preference, but in many cases, particularly in the public sector, there are regulations about how suppliers may be selected (Murdoch & Hughes, 2008). The Constitution of the Republic of South Africa (Act 108 of 1996) requires that public projects must be procured according to 5 requirements (Government of South Africa - Constitutional Law, 1996):

1. **Fairness**
   - All participants must be offered the same information. Offers and acceptance must not be bias.
2. **Equitable**
   - Only "blacklisting", lack of capability or resources, legal impediments and conflicts of interest can cause for a contract not to be awarded to a tenderer who satisfies all the requirements.
3. **Transparent**
   - The procurement process and all decision making criteria must be publicly publicised. All decisions and reasons for the decisions regarding the contract must be open to the public.
4. **Competitive**
   - It allows the industry to compete for a project (through tender processes) to ensure the project is awarded to an enthusiastic tenderer.
5. **Cost effective**
   - The system ensures the best value regarding the quality, timing and cost of the contract while ensuring the least resources are used to effectively manage and control the procurement process.

The aforementioned correlate to what was said by Willemse (2011) in **4.4.1.1.1**. It is worthy to mention at this point a report by Lædre et al (2006) on public building and construction projects in Norway. The study found that public owners continue to select the same procurement route as they are in the habit of. They do not consider what procurement route suits each single project, and therefore they do not select the route according to recommended practice. Innovation as a result becomes limited. The statements made by Willemse (2011) confirm that the situation in South Africa is the same. Furthermore, in response to studies in South Africa and Botswana on the inappropriateness of the traditional construction procurement system in the developmental context, Taylor et al (1999) states the following: “The traditional construction procurement system approach seems to be adopted where no one actively considers alternative procurement options; they simply fall back on that which they have used for years without considering how it may cope with changed conditions.”

Taking into consideration everything in this chapter thus far, it becomes very obvious that in selecting a procurement method, one has to take into account many different variables. It becomes much more complex than just time, cost and quality issues. In setting up a construction project, discussions and decisions are needed under each of the areas mentioned in the preceding section **4.4.2**. By working through each of the categories and making a clear decision or statement about the approach used in the project, the detail of the procurement method will be much clearer.

4.5.1 Choosing for Prefabrication

The delivery method selected by the client can have a large impact on the determination and extent of prefabrication. Kullman Buildings Corp (2008) state that four standard types of construction procurement are most relevant to modular construction: design-bid-build, negotiated bid, design-build, and strategic partnering. Although prefabrication can technically be used in any contract structure, most literature is in accord that prefabrication, pre-assembly, off-site fabrication and modularisation requires some sort of integrated contract strategy approach. *(Integration, as mentioned earlier, refers to a process whereby the design and construction processes of a project are interlinked. An integrated approach is therefore an approach where design and construction procedures ensue concurrently).* Some claim that the use of prefabricated building services calls for a restructuring of the complete traditional project delivery and supply chain system (Wong et al., s.a.), and that procurement routes are rarely chosen for their benefit to specific aspects of a project, but rather for the project as a whole (Mawdesley et al., s.a.).

Smith (2010) says that in any building project, the project team must determine early what the capacity of the project is to use off-site production, and that this requires a collaborative and integrative process of delivery. Luo (2008) is also of the opinion that integrated design and construction services help minimize the potential coordination problems along the supply chain and provides a good opportunity for prefabrication. One of the key elements in integrated project delivery methods, as mentioned in **4.4.1.2**, is the selection and participation of all the project personnel as early in the project as possible. This can only benefit the successful deployment of prefabrication. Buildoffsite's (2012) yearbook states how serial construction clients and their supply chain partners are becoming increasingly aware that traditional construction practises are unlikely to deliver the improvements they seek. The alternative strategy potentially adopted calls for integration of design and construction, and the increased use of off-site solutions.

Goodchild & Glass (2004) says that when prefabrication is utilised, the project manager should facilitate the involvement of contractors and specialists much earlier than is traditionally the case. Specialists should be appointed during conceptual design while structural options are still being considered. This allows committed specialist knowledge to be brought to bear at the time when options are being chosen. There may be contractual ramifications arising from this change, but design becomes a much more participative affair.

For contractors, early appointment allows them to be committed to a project with the confidence that their input will be rewarded. Design decisions are part-owned by the eventual constructors, which benefits the whole project (Goodchild & Glass, 2004).

In studying the effect of prefabrication on construction sequence, time and cost, Mawdesley et al. (s.a.) developed three modular suited procurement routes during the course of their research:

- **'Traditional'** Construction Procurement
- **'Hybrid'** Construction Procurement
- **'Ideal'** Construction Procurement

Traditional refers to separated and co-operative contract strategies as discussed in **4.4.1.1** where construction and structural design is not integrated, and the project team is fragmented. In the 'hybrid' process, initial structural design requires adaptation to accommodate off-site manufactured construction. There is greater co-operation between the members of the project team, although fragmentation is still evident. The 'ideal' method, however, is described as a process where all aspects of design, architecture, structure and construction are carried out in parallel, thus allowing greater integration and co-operation between members of the project team.

Another study by the University of Texas found that projects with collaborative relationships are more successful from both the owner's and contractor's perspectives (Geertsema et al., 2003). The selection-based model in which owners bring contractors to the table early in the design process, especially key subcontractors such as precast manufacturers, allows for decisions to be made regarding difficult portions of projects during the design phase, thus reducing costly changes later during construction **(Figure 3.2).**

It starts to become increasingly apparent that for prefabrication an integrated approach such as design-build, where the design and construction teams work in unison, is the best suited strategy. Also, Willemse (2011) mentioned that design-build is a very probable option which the Department of Transport and Public Works would consider. He claims that the Department of Transport and Public Works is ill-informed of the advantages such as cost and time, and that these need to be made clear. Future studies should dissect the design-build concept and provide a clear, concise description of aspects such as contractual arrangements, preparations of performance specifications and tender evaluation criteria.

As opposed to design-bid-build, design-build projects "reduce the overall project duration" (Grobler & Pretorius, 2002). Procurement methods such as design-build allow for early decision making regarding prefabrication systems that can lead to improved coordination and constructability, and finally reduced construction time. In addition, Songer & Molenaar (1996) found benefits of design-build in terms of cost and quality, an added benefit with prefabrication. Design-build also allows for the delivery process to potentially create a smoother flow of information between design and construction organisations. Instead of a handover method, where one group of individuals designs a facility and then simply transfers the responsibility to the next party, design-build methods can collaboratively identify prefabrication as the construction method and execute it as such.

According to Gibb (1999) the design-build approach enables early constructability input. In some cases, suppliers of off-site fabricated systems will offer services as design-build contractors, taking on board the traditional on-site construction work as well, usually sub-contracting this out to smaller contractors. Goodchild & Glass (2004) reaffirm this by proposing a 'lead frame contractor' role. This role could be undertaken by a multi-disciplinary firm, a precast manufacturer or an in-situ contractor. The Lead Frame Contractor could be large enough to undertake the whole frame package themselves or act as the single point of responsibility, procuring various work packages from other specialist suppliers, which might include precast manufacturer, in-situ contractors or even steel fabricators. The model moves away from the traditional relationship where specialist contractors are detached from the design process, and therefore specialists' knowledge can be brought to bear in working up concepts into viable schemes and help with detailed design and constructability issues.

Moreover, some major projects have been procured successfully in South Africa by design-build in recent times (Grobler & Pretorius, 2002):

- Saldanha Steel Plant (R800 million). *(Public)*
- Techno Centre for Vodacom in Bellville (R116 million).
- Prison at Louis Trichard (R300 million). *(Public)*
- Nelson Mandela Bridge in Johannesburg (R81 million). *(Public)*

These successful projects, most of which were in the public sector, provide confirmation that design-build does indeed fulfil the requirements posed by the South African Constitution for a procurement strategy mentioned earlier and that no special circumstances surround it.

Although design-build is well tested today, it has its problems in that it is usually architect or contractor led. The concern is that if the process is architect led, design will overwhelm values of production, and in a contractor-led model, construction will be the only consideration, finding ways to possibly reduce design features in favour of cost or schedule reductions (Smith, 2010).

Choosing a procurement approach for school construction is investigated hereafter.

4.5.2 Choosing for School Construction

School projects have features that are well-suited to prefabrication/modularisation. Classrooms allow for use of modular room design, and these projects also benefit from faster construction schedules. In the same study by McGraw-Hill Construction (2011) referred to earlier, industry professionals regarded education as one of the sectors that had the most opportunity for prefabrication, supported by the fact that it is one of the largest construction sectors by value (Carlisle, 2012). This is clear from the recent budget allocated to the Western Cape by the Members of the Executive Council. In addition to the annual budget allocation of approximately R770 million for educational infrastructure, National Education has made available a further R750 million in terms of the "Accelerated Schools Infrastructure Delivery Initiative". Thus the total educational infrastructure expenditure for the 3 financial years 2012/13 to 2014/15 will exceed R3 billion (Carlisle, 2012).

Willemse (2011) confirmed that most public school projects are delivered using the lump sum design-bid-build delivery method. This is also the case in the United States (Schaufelberger, 2000). A study was undertaken by Schaufelberger (2000) of project delivery methods used for private and public school construction in the US, the goal being to determine the suitability of alternate delivery methods in school construction. 30 public school districts were surveyed along with 21 private schools. The schools were surveyed to determine delivery methods used, issues with the traditional method, characteristics of preferred delivery methods, and reasons why alternate delivery methods have been used.

One of the first problems with the traditional method identified by Schaufelberger's study was that the project must be completely designed and contract documents prepared before soliciting for bids, the school district must clearly articulate its needs to the designer, and the designer must incorporate these requirements into the contract documents. Any changes during the construction typically result in cost escalation and construction delays. In this delivery method, the design is completed before the contractor is selected, precluding the use of the contractor's expertise during design development.

At this point it is of interest to refer to **Table 4.3**, a comparison of two schools, built in 1974 in the Dade County School District in Florida, United States. One school was constructed using the construction management procurement strategy and at the same time another was constructed with the design-bid-build (traditional) strategy. Although the results are difficult to compare directly to a South African context, it still provides some insight.

Project Characteristics	Construction Delivery Method	Traditional Delivery Method
Project Size	23 225 m^2	22 110 m^2
Construction Time	16 months	21 months
Project Cost	R 70 million	R 78 million
Cost per m^2	R 3 014	R 3 527

Table 4.3 - Comparison of School Projects (Schaufelberger, 2000).

Around the similar period, the San Diego Unified School District used a single construction manager to manage the construction of 10 elementary schools (Hanna, 1988). Five different architects were used to design the projects, and separate construction contracts were used for each facility. This 'partnering' approach was considered a huge success by the school board. 43 000 m^2 of new schools were constructed in 19 months. These results are yet again not very tangible from a South African perspective, but serve to provide a frame of reference.

The conclusion of the study by Schaufelberger (2000) was that the contractor should be appointed at an early stage so as to perform pre-construction services **(Table 4.3)**. Furthermore, the traditional project delivery method was found to be the most suitable approach when considering lower-cost simple school projects. A different approach, however, was suggested for larger, more complex projects. It was recommended that projects costing over about $2,5 million (R20 million) need to be constructed using a construction-manager-at-risk delivery method. This contract strategy was discussed earlier and was referred to as 'management contracting'. The distinct characteristic being that a single contractor undertakes all of the construction work. Design is done with the contractor already selected and hence the contractor can provide input at the design stage, so as to minimise constructibilty issues.

This method shares many characteristics with the design-build contract strategy, in that one contractor undertakes all construction work, but differs due to design-build also providing a in-house design team. It can therefore be deduced, that either one of these strategies would use the same methodology, and would achieve a very similar outcome. Design-build, or integrated contracts, can be selected to mitigate the seperation of construction from design which is the case in design-bid-build (Smith, 2010).

The government of South Africa recently adopted an Infrastructure Plan (Presidential Infrastructure Coordinating Commision, 2012) that is intended to transform the economic landscape of South Africa, to create a significant number of new jobs, strengthen the delivery of basic services to the people of South Africa and support the integration of African economies. The plan, first announced by President Jacob Zuma in his State of the Nation address in February 2012, lists 17 strategic integrated projects that cut across energy, transport and logistics infrastructure to schools, hospitals and nursing colleges. Of significance was Strategic Integrated Project 13:

- **Strategic Integrated Project 13:** National school building programme
    - A National school building program driven by uniformity in planning, procurement, contract management & provision of basic services.

The point here is that government is also seeking an integrated approach to solve the current socio-economic problems.

Furthermore, various procurement selection methods have been developed to help the client choose the most appropriate procurement system for their specific needs and situation (Ireland 1985; Skitmore and Marden 1988; Masterman 1992). However, some difficulties common to these studies are:

- Models seem to ignore some important factors in the selection of the most appropriate procurement systems.
- Some of the models are conditional and cannot be used by any client.
- Some of the models require the use of advanced mathematical techniques, which are considered to be time-consuming (Alhazmi & McCaffer, 2000).

It is, however, of interest to mention one of these models, namely the project procurement system selection model (PPSSM). This model is an integration of Parker's (Parker, 1985) alternative technique of value engineering and Saaty's (1994) analytical hierarchy process (AHP) into a multi-criteria multi-screening system. Four screening states were developed which range from the first rough screening process to the most detailed fourth screening. The result is an effective decision-making technique to systematically evaluate procurement systems against a number of criteria. The developed PPSSM causes the project team to discuss and determine needs from desires, the important from the unimportant, and trade-off from non-trade-off items. Hence, only the most promising systems proceed for further evaluation (Alhazmi & McCaffer, 2000).

A survey was conducted in Saudi Arabia with the aim of testing the PPSSM for effectiveness and efficiency and assisting the governmental agencies to select the most appropriate procurement system for implementation of their projects. The outcome of the survey indicated that public clients in Saudi Arabia selected design-build as the most appropriate procurement system for their projects.

In addition, **Appendix C** contains a case study of the Josiah Quincy Upper School in Boston, where design-build was successfully combined with precast concrete. 840m^2 of classroom space was completed in 4 months. Further case studies are contained in **Appendix C** showcasing successful implementation of prefabrication in school construction. Each case study claimed numerous advantages of which shorter schedules were most prevalent. Furthermore, all the case studies share one common characteristic – design and construction worked in parallel. The design-build procurement route continuously seems to be the obvious and preferred trend when it comes to prefabricated construction.

4.6 Conclusion

This chapter aimed to obtain not only an understanding of the term 'procurement' in the construction sense, but also an understanding of the various procurement methods available to a client. It was not the purpose to go into excessive detail on each method but rather to have a general idea of the concepts behind them. It was noted that in general, procurement strategies can be divided into 3 broader categories, namely: Separated; Integrated; and Management contracts. These were discussed as well.

Furthermore, the method of choosing a procurement strategy was examined, and it was here where it became apparent that this is a complex process, dependant on many variables – environmental, political, scope, etc. Some of these variables were discussed and it became clear that although owners, designers, and contractors may want to develop and use prefabrication, they are in many respects at the mercy of the context in which it is employed.

The literature used made it clear that there is no 'perfect' method for each situation, but rather an ideal solution for each projects unique characteristics. However, the intention of this thesis remains to determine the best manner in which to implement precast modular construction in the building of schools. Therefore, the aspects required of a procurement strategy to address this prerequisite were researched.

It was discovered from various sources that the use of prefabrication in construction calls for an integrated approach to the project, i.e. where design and construction services run concurrently. In addition, it was found that the same applies for when prefabrication is utilised in school construction, especially after schools were determined to be well suited to precast/prefabricated construction techniques **(Appendix C)**.

It could confidently be deduced from the literature that design-build, an integrated process, is the procurement strategy which is the best suited to both prefabrication, and when prefabrication is utilised in school construction. In addition, when viewed from a South African perspective, it was discovered that following a design-build procurement route could proceed with little to no difficulties, but on the contrary could be a welcome solution to current issues. Design-build satisfies all the requirements posed by the South African Constitution for a procurement contract and furthermore fits perfectly into the newly introduced Infrastructure Plan - which calls for integration of planning, procurement and contract management in addressing the crisis in the education sector. The issue however remains that current procurement routes are of the traditional kind, which needs to be restructured if prefabrication, along with a design-build approach, wants to ever be utilised.

Thus far, this dissertation has determined that precast modular construction is a viable, effective and proven alternative to traditional building methods of schools. It then exhibited how precast construction positively and negatively affected the construction principles of time, cost and quality. Additionally it was explored how it affected socio-economic, logistics and health and safety aspects, and was found to be overly advantageous, but nonetheless with some concerns.

This chapter supplemented the above, and the initial hypothesis, by introducing the notion that all of the aforementioned can be implemented optimally if the current procurement approach towards school construction is restructured, and a design-build approach is used.

However, this is not felt to be the most complete solution to the implementation of Precast Modular Construction in school construction. Other variables, specific to South Africa, need to be considered and addressed first. The Kullmann Building Corp (2008) was quoted as saying: "Four standard types of construction procurement are most relevant to modular construction: design-bid-build, negotiated bid, **design-build, and strategic partnering**." The emphasis here falls on the design-build and strategic partnership reference. These two concepts together are potentially a part of the broader solution – the rationale in this thinking being discussed in the next chapter.

In conjunction with the findings of this, and previous chapters and by combining it with the notion in the previous paragraph, **Chapter 5** aims to define and compile a complete solution for the successful implementation of Precast Modular Construction. This is accomplished by introducing the concepts of Standardisation and Strategic Partnering. The terms are explained and logic behind their introduction is discussed in the succeeding chapter.

Chapter 5

Standardisation and Strategic Partnering

5.1 Introduction

The previous chapter shows, via an extensive literature and case study review, that design-build is the best suited procurement strategy for implementing prefabrication. This is due to projects considering prefabrication requiring a project-wide integrated approach to both design and construction. Design-build offers such an approach. Furthermore, it was determined that design-build is also appropriate when the construction of schools is concerned, even more so when they are constructed using prefabrication techniques. However, to only recommend a single procurement strategy as the solution is insufficient, but instead the procurement strategy should be combined with factors that help address particular issues which are important in a South African context. For the purposes of this dissertation, and by no means a comprehensive list, these factors were determined as and are discussed in more detail in the remainder of the chapter:

- **Standardisation** – Repeated use of components, processes or methods
- **Strategic Partnering** – Long-term commitment between two parties for the delivery of a service.

The logic behind introducing these concepts is as follows:

Prefabricated components are essentially part of a manufacturing process which, similar to any factory produced product, works on the ‘economy of scale’ principle. This simply means that it becomes more economical the more is manufactured. In a South African market where prefabricated components are not used all that often, this is an issue. The point here is that although it is possible to construct a single school using prefabricated components, it is financially much more viable to the supplier/manufacturer if *many* buildings are built using their components. This suggests a concept of standardisation. However, standardisation suggests uniformity which is not ideal. Standardisation is therefore discussed in more detail further on and the concept of 'mass customisation' is discussed as well as a means of addressing the 'uniformity' issue.

Now, however, the issue becomes how to combine the principles and benefits of 'standardisation' with a design-build procurement strategy. This thesis suggests that forming a 'strategic partnership' between a client, design-build contractor and manufacturer is the optimal solution to the issue of implementing precast modular construction in schools. The concept of 'partnership', though, is extremely broad and many studies have been done on it (Bresnen & Marshall, 2000) (Gottlieb & Jensen, 2011). The information below only seeks to introduce the concept and explains its most fundamental facets and how these are beneficial to implementing precast modular construction in schools.

The concept of standardisation is discussed first.

5.2 Standardisation

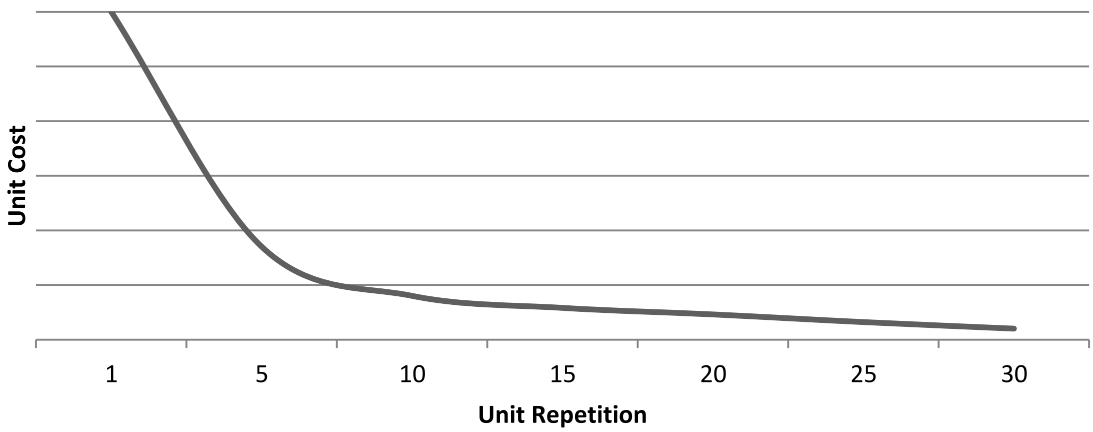

Figure 5.1 - Relationship between unit cost and unit repetition (standardisation) for precast concrete cladding (Gibb, 2001).

Factory based systems are not particularly suitable for bespoke one-off buildings and economies of scale are dependent upon large and regular orders. Where bulk orders are procured, cost savings are significant and benefit both supplier and manufacturer (Taylor, s.a.). Variability in the manufacturing process, such as the number of orders per day, can also cause the quality, delivery time and cost of that process to vary (Santos et al., 2002). This notion therefore implies that many of the same component or unit needs to be produced by the manufacturer in order to be cost, quality and time effective **(Figure 5.1).** This in part, implies standardised designs, or in other words 'standardisation'. In a study done by (Gibb & Isack (2001) on client drivers for construction projects and their implications for standardisation of processes and components, senior personnel from major construction clients were given the question asking how the standardisation of construction components and products could help them meet their business needs. Time, quality and operational benefits were cited for component standardisation. The most frequent comments were that standard components had lower costs, were of a given or proven quality and people knew how to use them. Furthermore, Gibb (2001) found that standardisation of products and components offered benefits from continual improvement as found in other industry sectors but often not realised with the one-off, unique project approach in construction.

The Construction Industry Research and Information Association defines standardisation as 'the extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice' (CIRIA, 1997). The Dictionary of Building defines industrialised building methods as:

> '…involving a high degree of prefabrication, often of the structural framing, roof, and cladding, so as to reduce site work to the minimum. This involves careful planning, and the maximum standardisation. The quantity of factory work on the building elements is deliberately increased so as to reduce the cost and improve the quality and speed of construction (Maclean & Scott, 2004).'

Utilising prefabrication for the construction of schools can be seen as innovative from a South African perspective, and innovation is often characterised by the widespread adoption of new practises (Lansley, 1996). Whilst its eventual impact will be a marked shift in the traditional or accepted pattern of processes and products within the industry, the conception often associated with innovation is continuous change. Edum-Fotwe et al (2004), however, suggest that the introduction of standardisation could assist in achieving consistency for the widespread deployment of innovation. Such consistency necessitates a stable system and structure (as well as procedures and processes). Standardisation therefore provides a degree of stability by, amongst other reasons, shortening of the learning curve associated with processes.

Standardisation and prefabrication are also considered by some as synonymous (Pasquire & Gibb, 2002). CIRIA (1997) found that whilst they can be used individually the greatest benefit is when they are used together and that benefits from advances in manufacturing industries can only be realised in construction where standardisation is accepted. The construction industry at-large is dominated by numerous small and specialized sub-contractors who typically are not technologically advanced enough to embrace automation. The sector that represents factory built buildings (the modular, prefab, panelised, precast, etc.) conversely is an exception (Neelamkavil, 2009). Therefore, since the products are built in factories, the principles of mass production and mass customisation that are the norm in manufacturing, apply. Egan (1998) also argues that construction is not very different from manufacturing. He states that many buildings, such as houses, are essentially repeat products which can be continually improved and, more importantly, the process of construction is itself repeated in its essentials from project to project.

Standardisation, however, has received a bad reputation amongst consumers due to the banal uniformity in lifestyle and landscape that standardisation offers (Smith, 2010) and it is due to this and other reasons that manufacturing has moved progressively towards mass customisation, overtaking the mass production process developed by Henry Ford and others for automobile manufacture in the first half of the twentieth century (Gibb, 1999).

Fordist mass production relies on the economies of scale in that as repetition increases cost per unit decreases, as illustrated in **Figure 5.1** above (Smith, 2010). Likewise as variation increases, the cost per unit exponentially grows **(Figure 5.2)**. Mass customisation, however, suggests that variability is possible within an acceptable margin of cost increase, illustrated below in **Figure 5.2**. Mass customisation allows for the benefits of mass production to be creatively combined with automated systems that offer greater choice for the individual customer, provide improved control of the total construction process, and flexibility of assembly options, and so works to preserve the benefits of variability and customisation in the output (Gibb, 2001). Gibb (2001) presents an argument in that whilst the parts may be standardised, the whole must provide variation – customised solutions from standardised components.

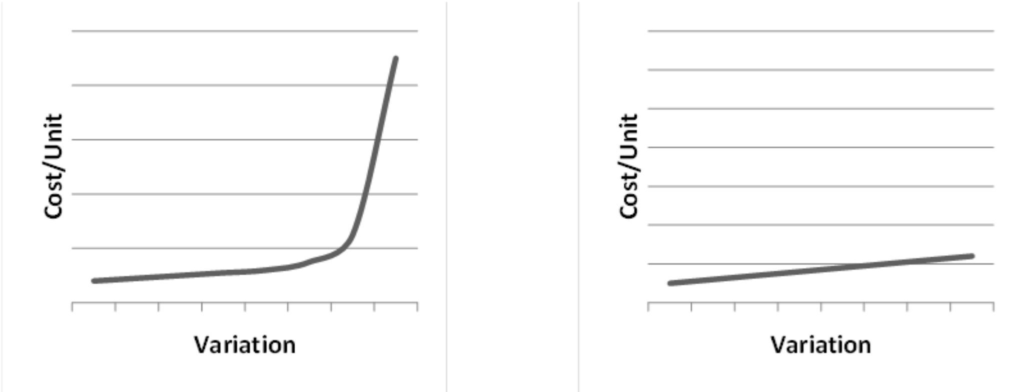

Figure 5.2 – Left: Variation and Right: Mass Customisation (Smith, 2010).

With electronic data interchange, high-powered computer-aided design, and digitally controlled manufacturing machinery there is no longer the necessity for 'identical' standardisation (CURT, 2010; Lu & Korman, 2010; Kaner et al., 2008). Mass customisation requires flexible production lines to produce a range of alternative assemblies to produce a variety of end-products which meet individual customer or project specific requirements. More effort is placed on the standardisation of interfaces between components which allows inter-changeability and maximises choice (Gibb, 1999). Standardisation has hence changed over the years with efforts now being made to meet clients' needs and produce customised individual buildings, yet still using standard components and employing standard processes to ensure success (Gibb & Isack, 2001).

There is therefore the full spectrum of tailored to standardised products available for prefabrication. Project teams must identify where benefit can be gained from choosing 'made for stock' rather than 'made to order 'items. The situation will depend upon the manufacturer's organisation and facilities. Referring back to **Figure 5.1** above, it shows the cost benefits for standardisation of precast cladding units. In this case the minimum repetition for cost-effective manufacture is around ten units with an optimum repetition of 30 units. After this the added benefit gained from more repetition becomes less significant, however with less standardisation the project will incur a cost premium. A similar graph could be drawn for other off-site fabricated items, but in each case the minimum cost-effective number will be different (Gibb, 1999). Additionally project teams will benefit from early involvement of the manufacturers to ensure that appropriate standardisation to suit each unit or component is adopted.

Standardised components together with a standardised design are discussed next.

5.2.1 Standardised Design

In effect standardisation implies many units or components that have the same dimensions and appearance. Utilising these components in different projects therefore calls for a standardised design of the respective buildings.

Standardised design can cover many aspects of the design of a school, or any other type of building. Standardisation can take place at many levels from processes, dimensional co-ordination of buildings, components, assemblies and modules. However, standardised design is often thought of in terms of a “template” or “repeat” design, and in its most simplistic interpretation implies a singular design solution for widespread implementation, the principal benefits of which are time- and cost-savings (CELE, s.a.).

Standardisation, internationally, rose to prominence during the post-war period through to the 1980s as a remedy to the growing need for school places. This happened in two ways. One was the creation of standard school plans and another, the development of industrialised buildings systems, particularly in the 1960s and 1970s (CELE, s.a.). From the early 1980s, as the volume of school building reduced, standardisation attracted less attention. However, it has returned to the agenda in recent years as economies have addressed a number of different issues from finding ways to construct buildings more efficiently by using prefabrication, to looking for ways of constructing buildings quickly and more cheaply.

For example, the Goldflex 100 Building System has been used for mass housing schemes in South Africa (Chief Directorate: Gauteng Provincial Department of Local Government and Housing, 2010). In this system, walls consist of storey-high, large, precast concrete panels joined together forming repetitive three dimensional units of one or more rooms. In the UK, standardised design is one of the recommendations of the report into England’s school building programme for the Department of Education by Sebastian James (James, 2011). This review recommends that "a suite of drawings and specifications should be developed that can easily be applied across a wide range of projects". The report argues that this does not mean that buildings will all look the same, the designs can be tailored. The aim is to both improve the efficiency of the process of building many schools, but also to facilitate feedback into the design of education environments through periodic reviews of these standard designs.

Laing O'Rourke and Atkins, two large UK engineering firms, have developed a model that uses standardised components that can be configured in a number of ways to create a bespoke school design, delivering them in 18 months (Construction Manager, 2011). The system is designed to meet the demands of James' (2011) review mentioned earlier, and is based on structural concrete panels. This includes the floor, some internal walls and the building envelope. The precast external panels include a variety of window and architectural treatments and can also feature a brick or stone finish. Precast concrete columns are used to reduce the need for internal structural walls; instead, dry lining is used for partitioning as this offers the greatest degree of flexibility and means the school can be easily reconfigured as well (Lane, 2011).

The two engineering firms in their collaborative endeavour claim that their system can deliver secondary schools for about 30% less than the cost of a conventional built school. A 1,300 pupil school is projected to cost £14.4 million (R187 million), £6 million (R78 million) less than a conventional school. The firm claim the school would be £70,000 (R910 000) cheaper to run over its life as well, as it is billed as using half the energy of a school built in a traditional manner, and also that the inherently robust nature of concrete would mean it should be cheaper to maintain. They also claim that via their system a typical school programme of 70 to 80 weeks could be reduced to 52 weeks (Lane, 2011). Nevertheless, critics of a standardised system still exist.

Critics of standardised design cite it as being inflexible: It thwarts innovation and fails to address diverse educational and other needs of communities (Chief Directorate: National Department of Human Settlements, 2010). However, there are examples from some countries that suggest that developing best-practice "standardised designs" and modular construction methods can be cost-effective, and reduce design and construction costs while producing a range of tried and- tested educational environments that support teaching and learning (CELE, s.a.). In the face of tightening budgets and increasing demand on governments to provide learning environments that support the development of 21st century knowledge, skills and attitudes, standardised design could be a model for the future.

Now that Standardisation has been discussed, Strategic Partnering is explored as supplementary to the theme of this chapter.

5.3 Strategic Partnering

One of the principal issues identified by James (2011) in his Review of Capital Education, with the current system of school construction, is the lack of learning and systematic improvement of quality, cost and time from one school building project to another. This has been caused directly by the design and procurement process which has resulted in most schools designs being ad-hoc. Among the many knock-on problems that this has created are high costs (of both design and construction), variable quality, a need for every school to pass through an arduous cycle of checks and balances, and no opportunity for improvement.

Moreover, Egan in his Rethinking Construction Report (1998) states that the conventional processes assume that clients benefit from choosing a new team of designers, constructors and suppliers competitively for every project they do. Instead he says that on the contrary repeated selection of new teams inhibits learning, innovation and the development of skilled and experienced teams. Critically, it prevents the industry from developing products and an identity - or brand - that can be understood by its clients.

It starts to become evident that what is required is for teams of designers, constructors and suppliers to work together through a series of projects, continuously developing the product and the supply chain, eliminating waste in the delivery process, innovating and learning from experience. Smith (2010) agrees and states that continued alliances that join for multiple projects can yield better results the second or third time around.

This can further be extended to the use of prefabrication. Smith (2010) claims that a client and contractor, who build together often, may find prefabrication beneficial because the systems that are developed may be employed in other projects. This is especially true for project teams that work together on a series of building ventures. The added benefit is that project team members also continue their relationship with the fabricator, who may or may not be the contractor, but becomes a key player in delivering the facilities. Research has suggested that performance, in terms of cost, time, quality, constructability, fitness-for-purpose and a whole range of other criteria can be dramatically improved if participants adopt more collaborative ways of working (Bresnen & Marshall, 2000).

Consequently, a good deal of attention has been directed towards examining the issues mentioned above, and as result the concept of 'partnering' comes to the foreground. The Latham (1994) report perhaps has proved to be the most significant milestone in the UK construction industry; in that it indicates for the first time that the public sector should change procedures and methods to incorporate the concept of 'partnering'. In his report, he states the following:

> Specific advice should be given to public authorities so that they can experiment with partnering arrangements where appropriate long-term relationships can be built up. But the partner must initially be sought through a competitive tendering process, and for a specific period of time. Any partnering arrangements should include mutually agreed and measurable targets for productivity improvements (Latham, 1994).

Literature furthermore reveals that partnering is not a unified concept (Cox & Townsend, 1998). It takes on a number of different forms, including: project partnering; and strategic/full partnering. The main differentiating feature between these is the relationship duration. Project partnering is project specific and one-off, while strategic partnering is characterised by longer term arrangements. For the purpose of this dissertation, we will only consider strategic partnering, as it is deemed by the author capable of addressing and aiding in forming a complete solution for the implementation of Precast Modular Construction.

The most commonly cited definition for strategic partnering is that proposed by the Construction Industry Institute (1999):

> A long-term commitment between two or more organisations for the purpose of achieving specific business objectives, by maximising the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organisational boundaries. The relationship is based on trust, dedication to common goals, and an understanding of each other's individual expectations and values. Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and services (CII, 1999).

Strategic partnering takes place where two or more firms use partnering on a long term-term basis to undertake more than one construction project. It is generally accepted that strategic partnering relationships accrue benefits on individual projects, but the scale of the benefits increase as each project undertaken profits from the lessons learnt from previous projects. Strategic partnering provides the full benefits of partnering because it allows for continuous improvement (Matthews, 1999).

Departing from the clinical definition, 'Partnering' is simply a relationship wherein (Cook & Hancher, 1990):

- all seek win-win solutions,
- value is placed in long-term relationships,
- trust and openness are norms,
- an environment for profit exists,
- all are encouraged to openly address any problem,
- all understand that neither benefits from exploitation of the other,
- innovation is encouraged,
- each partner is aware of the other's needs, concerns, and objectives, and is interested in helping their partner achieve such.

A typical partnering relationship involves an element of commitment and is probably the most important component in establishing a partnering relationship. The partnering companies must commit to a long-term relationship in which each company understands the goals of the partner, and each exhibits a real commitment to seek new ways to assist the partner in achieving its goals and in gaining a competitive advantage. A long-term relationship creates an atmosphere that allows companies to achieve a competitive advantage by addressing problems in areas that require extensive time to solve or that require constant improvement (Morgan & Dowst, 1988).

The commitment to a long-term relationship results in a partnership that is not in a state of constant reassessment and in which each partner has a clear focus on continuous improvement of the relationship and dedication to common goals. Such a commitment will provide a synergistic environment that encourages trust and openness and empowers individuals to employ breakthrough thinking in a supportive environment (Morgan & Dowst, 1988).

Partnering implies that the commitment should not be dependent on individual personalities to maintain the relationship. Partnering signifies a clear intent to maintain a functional organization between the partners, and partnering implies a long-range relationship over many projects. An inevitable aspect of the construction industry is that project managers and supervisory personnel come and go, and the changes resulting from management turnover impact the schedule, cost, and quality of a project. A partnering agreement can minimize the adverse effects on the project caused by supervisory personnel turnover because interfaces between the two companies are developed at more than a single level and for more than a single project. Although personnel changes may occur, the commitment from partnering will maintain the momentum of the relationship (Cook & Hancher, 1990).

Partnering, however, is not suitable for all kinds of projects. In small, one-off, less complex projects which are of low strategic importance, the set-up costs simply do not justify an extensive collaborative approach (Eriksson, 2010). Kullman Buildings Corp (2008) states that strategic partnering is ideally suited to projects characterised by high volumes of repetitive work. Seeing how school construction is exactly this, it is sensible to agree that strategic partnering makes sense from a school construction perspective. The benefits of strategic partnering are hereafter discussed.

5.3.1. Benefits of Partnering

The most prevalent benefits of partnering for the project owner or client are as follows (Matthews, 1999):

- Reduced exposure to litigation through open communication and issue-resolution strategies.
- Lower risk of cost overruns and delays because of better time and cost control over projects.
- Open communication and unaltered information allow for more efficient resolution of problems.
- Increased opportunity for innovation through open communication and the element of trust, especially in the development of value engineering changes and constructability improvements.

These benefits may seem intangible, but the Arizona Department of Transportation (ADOT), the Texas Department of Transport (TxDOT), and the United States Army Corps (USAC) have reported significant tangible benefits from implementing strategic partnering. A connection between these sets of results lies in the fact that all of the projects in question were undertaken within the public sector. (*Once again, these case studies are merely a frame of reference, and cannot directly be compared to a South African context. Nevertheless, they are useful to show examples of successful implementation.*)

The ADOT, according to Matthews (1999), reported that 120 partnered projects achieved the following benefits:

- An average time saving of 12%
- Value engineering savings of 3%
- Total cost savings of 20% (percentage of bid amount)

The TxDOT similarly claim the following results for 210 partnered projects (Grajek et al., 200):

- A 14% decrease in schedule duration

- Reduction in the number of claims and disputes on projects
- Better communication, better teamwork, increased trust, and stronger relationships

These results are supported by the benefits achieved by the USAC. USAC reported that 16 partnered projects produced a mean cost change of +3 per cent, 6 per cent lower than that of non-partnered projects. Also variations on partnered projects were 4 per cent lower than those on non-partnered projects. However, more significantly, claims cost were 4 per cent lower than on non-partnered projects (Weston & Gibson, 1993). Furthermore, they found that using 'partnering' results in an 80–100% reduction in cost overruns, virtual elimination of time overruns, 75% less paperwork, significant improvements in site safety and better morale.

In the United Kingdom, Many companies have reported radical successes with partnering arrangements. Rover Group and SDC Builders (Naoum, 2003) partnership resulted in a long-term relationship from 1990 onwards with over R900 million of work by value being carried out without a formal contract. Bennett & Jayes (1997) holds Sainsbury (a major supermarket chain producing some 25 stores per annum) as an outstanding example of success in partnering. They cite tremendous savings in time and cost and go on to claim that strategic partnering can achieve savings of 30 per cent over time (Bennet & Jayes, 1995). A similar outcome was experienced with the Nepean's (R145 million) Hospital extension in western Sydney, Australia, where the project was completed early and below budget under the partnering concept (Naoum, 2003).

Furthermore, precasting and partnering was successfully combined on two office developments in London (Interface, 1999). The steel frame contractor, mechanical and electrical contractor, and cladding contractor were appointed at the earliest design concept stage so that the interface of structure, cladding and services could be addressed from the outset. As a result of lessons learned on the previous project, and because the same team was still in place many benefits were claimed.

Another study by Matthews (1996) identified that subcontractors quote approximately 10% lower on partnered projects than on non-partnered projects. Also, the greater stability in workload associated with long-term partnering helps companies deploy their resources more effectively and makes them more likely to invest in training and research (Bresnen & Marshall, 2000).

However it is unclear in many cases how the benchmarking was established or that traditional methods of saving costs could not have equally resulted in similar savings. Nevertheless there appears to be evidence that major clients are satisfied with results and have in some cases achieved continuous improvements (Naoum, 2003).

Now that the benefits of partnering have been established, in order to remain objective the risks are now discussed.

5.3.2 Risks of Partnering

Despite the potential advantages and benefits derived from a partnering relationship, partnering entails risks that each company must evaluate. A partnering relationship is not a casual pairing of companies. A successful partnering relationship requires that each company understand the other's objectives, business strategy, and how the relationship will provide a competitive advantage (Kearney, 1987; Morgan and Dowst, 1988).

As many companies have experienced through traditional business relations with customers and suppliers, company weaknesses and insufficiencies are accentuated by mutual dependencies (Conrads, 1983). The partnering concept is intended to accentuate the strengths of the partners and as a result cannot compensate for fundamental weaknesses in a company. An improperly structured partnering relationship tends to magnify a company's internal faults.

Each company must evaluate its risk if the partner does not perform according to the company's perception of what the agreement requires. For example, the constructor or engineer must evaluate the level of resources to commit to the relationship and the resulting risk to the firm for this commitment should the partnership fail. An owner must evaluate the risk of proprietary information not protected by patents falling into the hands of competitors (Cook & Hancher, 1990).

The Construction Industry Institute's Partnering Task Force in the United States has identified some major concerns that construction owners, constructors, and engineers have about partnering relationships. These concerns include the following (Construction Industry Institute (CII), 1999):

- Protecting proprietary information
- Evaluating and assuring of value received
- Equitable sharing of risks by all parties
- Obtaining and maintaining total commitment
- Creating a strong dependency on the partner
- Limiting competitive market strategy
- Integrating different company cultures

Ng et al. (2002), after a study on Australian Government construction projects, found that most problematic issues experienced in partnering involve the failure of stakeholders to develop the required attitudes to make partnering effective. This is strongly influenced by the client, who was perceived by all the respondents in the study as not having the level of commitment or leadership required to draw the full commitment of contractors to the partnering arrangement, throughout the entire duration of the projects. This indicated that the public clients were not providing the support required for effective implementation of the partnering arrangement. As the clients are in the position of the head facilitator of the partnering arrangement, they must take a leadership role, and ensure that they are fully committed and prepared to compromise in the partnering arrangement. In other words, the Public client should be willing to amend and adjust current policies and procedures.

5.4 Conclusion

This chapter introduced two new concepts: Standardisation and Strategic Partnering. These concepts were introduced strategically, as they develop and work towards verifying the initial hypothesis of this dissertation - that precast modular construction is a feasible and effective method for the delivery of school buildings in South Africa.

These concepts were found to have diverse meanings and interpretations, but this chapter intended to allocate definitions that pertain to the overall theme of the study. In other words, partnering and standardisation can mean many different things and many studies have been attempted to define them, but for the purpose of this thesis, partnering and standardisation were viewed from a prefabrication standpoint and how they relate as such.

Standardisation was discovered to be predominantly perceived as a repetition of components, all having similar dimensions and hence leading to a bland uniformity in the end product. This is an inherent characteristic of the mass production concept, whereby large production numbers decrease capital costs. However, this approach is unfavourable and especially so when building schools. The consumer seeks a unique solution to his situation, and therefore the concept of mass customisation was introduced.

Mass customisation combines the principles of mass production and automation to create a manufacturing process whereby standardised components can be tailored to each specific project but also addresses the need of the manufacturer for a constant flow in the production line. Prefabrication can therefore become feasible and sustainable. In South Africa, the school building can be viewed as a beacon or symbol that uniquely defines a community, especially in rural underprivileged situations. In other words, a school building with its own unique character is required. Mass customisation can potentially achieve this all while still attaining the benefits prefabrication offers.

In addition, standardised designs consisting of a suite of drawings and specifications that can easily be applied across a wide range of projects, was seen as a potential complementary solution. It is argued that this does not mean that buildings will all look the same but rather that the designs can be tailored. The aim is to both improve the efficiency of the process of building many schools, but also to facilitate feedback into the design of education environments through periodic reviews of these standard designs.

Strategic partnering was then explored, along with its benefits and potential risks. This concept proposes a long-term relationship between a client, contractor and manufacturer for the construction of more than one project. All the literature agreed that this leads to cost, time and quality advantages, but most importantly it leads to increased innovation in that knowledge and experience is gained from each successful project. The current procurement approaches in South Africa, results in a new project team being selected for each new project. This inhibits innovation and detrimentally so when the project is new and innovative, which would be the case should Precast Modular Construction be used in school construction.

Up to this point, this study has achieved in proving the creditability of precast concrete as an alternative for school construction, showcasing successful examples along with all the benefits and inherent characteristics of prefabrication. Design-build was in addition determined to be the most suitable procurement method for the implementation thereof. But it was not felt sufficient as a complete solution and the aforementioned concepts of standardisation and strategic partnership was introduced.

To clarify how these concepts aid to the general theme of this study, the next chapter embarks on a discussion as to how the integrated approach of a design-build procurement strategy; standardisation of components; and strategic partnering can be combined to create a complete solution for implementing Precast Modular Construction in South Africa for school construction. An all-encompassing proposal that addresses many issues found during the study and prevalent in the South African market, such as employment, and an ill-informed and inefficiently sustainable precast manufacturing industry.

Chapter 6

Implementing Precast Modular Construction: A Discussion

6.1 Introduction

The preceding chapters provide a background to the various aspects considered by this dissertation as essential to implementing a precast/prefabricated solution to the construction of schools in South Africa. Prefabricated precast components were examined so as to determine *what* is available to the design team and that precast concrete is a viable alternative to traditional construction, whereafter a preferential procurement strategy for the implementation thereof was investigated. It was ascertained that for the optimal application of prefabrication, an integrated procurement approach is demanded, such as design-build, whereby design and construction processes occur in parallel.

This finding however was determined not to be sufficient as the complete solution to the problem, but rather a broader all-encompassing approach is needed. The purpose of **Chapter 5** was to introduce the facets considered necessary in achieving such an approach, namely: Standardisation and Strategic Partnering.

This chapter proposes how these concepts, together with design-build and precast construction, can be combined in a logical manner and in the process provide a solution to implementing precast modular construction in the South African school building industry.

The chapter is predominantly written in the author's own hand, as this proposed approach contains no documented examples of implementation in South Africa and therefore literature on it is severely limited. The rationale behind the author's proposal is presented in the most logical and coherent manner possible. All the claims and facts stated in this discussion were looked at in more detail in previous chapters. In other words, if a statement or claim is made below, it was researched and cited in a previous chapter.

6.2 Discussion

The use of prefabricated precast components is not an entirely new concept in the South African market. Various manufacturers of precast components exist and their products have been used on many projects. Elements range from hollow-core slabs, sandwich panels, columns and beams, to complete modules. However, the use of prefabricated precast in the construction of school buildings is rarely attempted in South Africa **(Figure 2.8)**. This is contrary to the international arena where the use of prefabrication is commonplace and more than often considered for use in the construction of schools. Some alternative technologies, such as foam or polystyrene wall panels, have been considered and implemented, but these methods are mostly avant-garde, and are generally negatively perceived by previously disadvantaged communities. The reasons for this are multifaceted and were discussed in **Chapter 3**, but seeing that these communities are the most in need of educational facilities, their outlook cannot be ignored.

Precast concrete directly addresses this issue by providing an 'air' of quality, strength and status. Even if they notice the difference in construction techniques, concrete is nevertheless a material that communities can relate to and hence alternative implementations thereof will be easily accepted by them. This dissertation recognised this and therefore focused on the use of precast concrete in construction.

Precast concrete was moreover found to be a very versatile concept, as many applications and variants of it exist. These were discussed in detail in **Chapter 2** and included hollow-core slabs, precast walls, beams and columns, and tilt-up**.** Examples of its applications range from commercial to residential, and more importantly schools. This was proven by showcasing 4 international case studies of where precast concrete was used successfully in the construction of schools. Precast concrete was hence determined and proven to be an effective and viable option in the construction of a school.

Furthermore, precast concrete construction was identified as being merely an extension of the ideas and principles associated with prefabrication. This means that it is something that is factory produced, sometimes on-site, to be assembled at the project location. Many advantages are associated with prefabrication and this was looked at in detail in **Chapter 3**.

In addition, it was discovered that when prefabrication is considered for a project, the decision needs to be made at an early stage in the project life-cycle. Making the decision at later stages tended to complicate the construction process, resulting in design and construction issues and delays. When the decision to use prefabrication is made by either the client or contractor, it requires all the parties in the project to be aware of this decision at an early stage, i.e. clear communication is essential early on. An 'integrated' approach is hence required where the client, designer, contractor and supplier all work together. With an integrated model, decisions regarding prefabrication can be made up-front so that problems are identified early and appropriate solutions can be found that meet the conceptual, economic, environmental, and social requirements of the building project.

The level of co-operation and communication, i.e. *integration,* between the client, designer, contractor and supplier was discovered to vary depending on the procurement strategy chosen. Different procurement strategies offered different advantages, but in order for an 'integrated' approach to ensue, it requires a contract strategy that is designed to accommodate maximum collaboration between the respective project parties.

Gibb (1999) was in agreement and was of the following opinion:

> In order to realize the maximum benefits of prefabrication, a project-wide strategy must be developed at an early stage in the process. Integrated practise is a project-wide strategy that depends on the delivery method (contract strategy) defined from the very beginning and conceptually brings all the players to the table in order to innovate.

After an extensive literature review, the ideal contract strategy was determined to be the *design-build* approach. This procurement route facilitates the co-operation of the design team, which is sometimes in-house, and the contractor. It was discussed in more detail in **Chapter 4**.

It was found, however, that to merely specify an integrated contract strategy was not the end-all solution to implementing precast modular construction for schools in South Africa. A few problems arose that needed addressing, namely:

1. For a precast manufacturer and the overall project, it is not optimally viable to produce one-off unique precast components for a bespoke single project.

2. Less work on-site means less people on-site which, although beneficial from a safety and cost perspective, allude to job-loss from a South African perspective.

3. Seeing as how using prefabrication to construct a school building is an innovative process (in the South African context), the skills and experience gained by completing such a project is lost if a new design-build contractor is selected for each new project.

The concepts in **Chapter 5** were intentionally introduced and together with a design-build contract strategy, directly address the aforementioned issues.

Standardisation was discovered to be predominantly perceived as a repetition of components, all having similar dimensions and hence leading to a blatant uniformity in the end product. This is an inherent characteristic of the mass production concept, whereby large production numbers decrease capital costs. However, this approach is unfavourable and especially so when building schools. The consumer seeks a unique solution to his situation, in other words a community would prefer a school with its own unique characteristics and therefore the concept of mass customisation was introduced.

This concept combines the principles of mass production and automation to create a manufacturing process whereby standardised components can be tailored to each specific project but also addresses the need of the manufacturer for a constant flow in the production line. Prefabrication can therefore become feasible and sustainable.

Moreover, standardised designs - consisting of a suite of drawings and specifications that can easily be applied across a wide range of projects - were found as a potential complementary solution. It is argued that this does not mean that buildings will all look the same but rather that the designs can be tailored. The aim is to both improve the efficiency of the process of building many schools, but also to facilitate feedback into the design of education environments through periodic reviews of these standard designs.

Strategic partnering, in addition, was found to be an approach where all the key suppliers and contractors are employed by the client or developer for a number of years and for several projects. Different contractual conditions apply, but generally there is an agreement to provide services or products for an agreed fee or cost (which may vary based on a number of criteria). In this way, once a partnering agreement is in place, precast or other constructability expertise can be obtained from suppliers and manufacturers at an early stage in any one of the projects covered by the agreement.

6.2.1 Proposal

On the basis of the aforementioned, this thesis aims to provide a link between all of the said theory and is given the verification it needs to present the following proposal as a manner of implementing precast modular construction for schools in South Africa:

> ***A single design-build contractor is awarded by the Department of Public Works a contract, via competitive tendering, for the construction of a predetermined number of schools, preferably exceeding 3, over a given contract period using a standardised design and utilising customisable standardised prefabricated precast construction systems, i.e. Precast Modular Construction.***

This proposal addresses the subsequent vital issues in the following ways:

I. 'Economy of Scale'

- The economies of scale principle is satisfied and standard prefabricated components can therefore be manufactured or 'mass customised' in the most feasible way possible.
- A standardised design which can be tailored to each specific project will facilitate feedback into the design of education environments through periodic reviews of these standard designs, and reduce unnecessary design and construction costs.

II. Employment

- Precast manufacturers will have a confirmed number of orders for products, and can hence be assured of a constant flow of income. This translates directly to an increase in both employment and job security at the manufacturing plant.
- The design-build contractor will be guaranteed employment for a given period, once again providing job security for its employees, of which the

number can also potentially increase. In addition, this will result in sustained training and skills development.

- The design-build contractor can satisfy further employment opportunities by employing local labour in each project location to complete the on-site work such as foundations, site clearance, etc.
- 'Satellite' factories can be temporarily set up at the project location, and so create employment for the community and in doing so it generates a situation where the project is done '*by the community, for the community*'.

III. Lack and loss of skills and expertise

- The 'strategic partnership' formed between the client and design-build contractor after a successful open tender, the designer, and supplier creates a situation that stimulates innovation. Methods and techniques can be tested with each party being fully aware of their respective roles, due to the clear lines of communication design-build and strategic partnerships offers.
- Due to not being limited to only one project, the design-build contractor carries with it experience and lessons learned from each successfully completed previous project on to the next, and so becomes more proficient, resulting in better, higher quality schools delivered in shorter periods and with increased efficiency. Systematically an industry knowledgeable and proficient in precast construction will be created.

In addition, the following will also potentially result:

- A monopoly is prevented by ensuring that the tender is awarded on a competitive basis.
- The use of precast concrete will reduce the overall project duration dramatically, thereby providing the client with schools ready for use in shorter periods of time.
- Communities easily adopt the innovative projects due to the assurance in quality and status that accompanies precast concrete construction, i.e. concrete as a material.

Nevertheless, some **barriers** exist along with certain constraints which could encumber the successful application of the above proposal and negate some the potential valuable results. Some of these barriers are as follows:

- The extent, to which precast concrete is used, is partly subject to the capabilities, facilities, expertise and skills available to the project team. Due to the scant use of prefabrication in the South African industry, specifically precast concrete, these factors might be found wanting.
- As discussed in **Chapter 2**, the current South African design codes and standards do not provide sufficient guidance in the design of structural precast concrete construction. This limits the extent to which it can be implemented, as insufficient technical guidance places restrictions on the designs of architects and engineers.
- For a design-build procurement strategy to succeed, a clearly defined scope is required. The client, in this case the Department of Public Works, will need to be knowledgeable of the strategy and clearly state what the requirements are.

The above constraints are however not impossible to address, and can be accomplished as follows:

- By repeated **instructed** use of precast concrete and prefabrication construction systems, a knowledgeable industry will eventually be created. A knowledgeable industry will demand the most efficient solution to problems, which precast concrete has the potential of being - and so create a demand for precast products. A demand will necessitate a supply and systematically a sustainable precast industry will result.
- The current design codes are in the processes of being changed to a South Africanised version of the Eurocode. This code is much more comprehensive than the current SANS 10100-1 and provides ample guidance in the use of precast concrete construction.
- Through proper education of the benefits and contractual ramifications associated with a design-build strategy, the Department of Public Works can become knowledgeable and hence understand the requirements of the strategy, such that a clear, well-defined scope should be compiled.

By addressing the said potential problems, the aforementioned proposal has no reason why it cannot succeed. In a socio-economic situation such as the one in South Africa, where large numbers of schools are required quickly and of high quality, the above proposal is logical.

6.3 Conclusion

This chapter took all the components researched in the preceding chapters and combined them to formulate a proposed concept for school construction. This proposal provides a logical solution that introduces the use of prefabrication, and all its advantages, but at the same time addressing the situation specific characteristics of South Africa. The results that would theoretically be attained from using the aforementioned approach were mentioned as well.

The next chapter provides a summary of the findings in this dissertation along with recommendations for further studies.

Chapter 7

Conclusion and Recommendations

This chapter discusses the main findings that were obtained in the study by drawing together the results from the previous chapters. A conclusion of the theory and deductions is presented, followed by recommendations for future research endeavours.

7.1 Conclusion

Prefabrication using precast concrete is a far reaching and versatile concept. Many applications and combinations thereof exist. The term 'Precast Modular Construction', which appears in the title and initial hypothesis, is in essence also just an extension of the ideas and principles associated with prefabrication, and was coined strategically for the purpose of this study. The term was defined as a combination between precast concrete – a construction product produced by casting concrete in a reusable mould or "form" which is then cured in a controlled environment, transported - if required - to the construction site and lifted into place (e.g. Hollow-core slabs, wall panels, beams, etc.); and precast modular – substantially complete precast concrete modules resembling blocks. The term was therefore restricted in that only application in *concrete* was explored. Many options were determined to be available to the designer, and the first part of this study aimed to merely introduce all the various applications and components - arguing that the best combination and utilisation of the components will be the preference of the designer and contractor, and to a degree determined by each unique project.

Furthermore, this concept was found to bring numerous benefits to the construction industry. Many literature references state how using prefabrication amounts to considerable savings in time. Earlier completion times as a result allow for earlier occupation. Logistics, that is transportation to the site, was also found not to be an issue in South Africa.

To not understate the other benefits such as improved quality and improved safety, the time benefit of prefabrication is the key to its success. Especially when considering it for the construction of schools. **Appendix C** in addition showcased 4 successful utilisations of precast concrete in school construction, acting as evidence that precast concrete is indeed a viable and proven alternative to traditional construction methods

This dissertation recognised the aforesaid notion, and consequently developed a proposal for the implementation of precast modular construction in the South African school building industry. The motivation being that in a socio-economic situation such as the one in South Africa, it makes sense to find a process whereby numerous schools can be built quickly and of high quality.

The proposal for this process came to realisation after a number of obstacles had been identified while conducting research. These were as follows:

1. The current procurement model in use for public procurement projects, specifically school construction, does not lend itself to optimal integration amongst the client and project team. Prefabrication requires an integrated contract strategy for optimum implementation.
2. Previously disadvantaged communities do not readily accept alternative building materials beyond brick, mortar and concrete.
3. South Africa does not have an overly sustainable precast manufacturing industry, which can viably endure random or one-off prefabricated projects.
4. When a school is innovatively constructed by a contracting and design team using precast concrete, the current system of tendering for public projects means a new contractor and design team would most likely be selected for successive projects, resulting in the experience and knowledge learned from the previous project being lost and not taken advantage of.
5. The non-labour intensive nature of prefabricated construction, although beneficial from a cost and safety perspective, may directly implicate job-loss from a South African perspective.

For these reasons and after an extensive literature review during the course of this dissertation of several precast systems and options available in South Africa and internationally and successful applications thereof, the author combined the principles of design-build procurement, standardisation and strategic partnering, and obtained the verification needed to develop the following proposal as a remedy to the above problems. *(The rationale in deducing this proposal was discussed in* ***Chapter 6****).*

> ***A single design-build contractor is awarded by the Department of Public Works a contract, via competitive tendering, for the construction of a predetermined number of schools, preferably exceeding 3, over a given contract period using a standardised design and utilising customisable standardised prefabricated precast construction systems, i.e. Precast Modular Construction.***

This proposal will theoretically be able to address the said obstacles in the following ways:

1) The design-build procurement strategy is a contract strategy which allows for maximum integration of the contractor, designer, supplier and client. A situation ripe for prefabrication and innovation.
2) Precast concrete is a material any community readily accepts.
3) Allowing for the contract period to extend beyond not one, but a minimum of three projects, permits the precast manufacturers with certainty in demand and supply. Hence, becoming more viable.
    - In addition, the use of standardised designs and components results in a situation where unnecessary design and constructions costs are saved, and a 'template' of a school is created which is tailored/customised for each individual project. This also indirectly addresses the 'economy of scale' principle important to precast manufacturers.
4) The extended contract allows for the design-build contractor to carry lessons learned from previous projects over to the next one, in the process becoming more proficient and innovative.
    - Also, the strategic partnership created between the client and design-build contractor after a successful bid, will lead to cost, time and quality

advantages, but most importantly it will lead to increased innovation in that knowledge and experience is gained and shared from each successful project.

5) The security offered by the extended contract period allows both the manufacturer and contractor to increase employment as work is guaranteed. In addition, the manufacturing plant allows for individuals to gain a permanent skill. The local labour will also benefit from the guarantee of construction.

The proposal, in addition, accounts for some other potential weaknesses:

a) A monopoly is prevented by keeping the tender process competitive. Only the best bid is selected, with the Department of Public Works deciding the criteria by which it is selected.

However, the above proposal will most likely be encumbered by the following constraints:

I. The extent, to which precast concrete is used, is partly subject to the capabilities, facilities, expertise and skills available to the project team. Due to the scant use of prefabrication in the South African industry, specifically precast concrete, these factors might be found wanting.

II. As discussed in **Chapter 2**, the current South African design codes and standards do not provide sufficient guidance in the design of structural precast concrete construction. This limits the extent to which it can be implemented as insufficient technical guidance places restrictions on the designs of architects and engineers.

III. For a design-build procurement strategy to succeed, a clearly defined scope is required. The client, in this case the Department of Public Works, will need to be knowledgeable of the strategy and clearly state what the requirements are.

These constraints however are not particularly problematic to address.

i. By repeated **instructed** use of precast concrete and prefabrication construction systems, a knowledgeable industry will eventually be created. A knowledgeable industry will demand the most efficient solution to problems, which precast concrete has the potential of being - and so create a demand for precast products. A demand will necessitate a supply and systematically a sustainable precast industry will result.

ii. The current design codes are in the processes of being changed to a South Africanised version of the Eurocode. This code will be much more comprehensive and will provide ample guidance in the use of precast concrete construction.

iii. Through proper education of the benefits and contractual ramifications associated with a design-build strategy, the Department of Public Works can become knowledgeable and hence understand the requirements of the strategy, such that a clear, well-defined scope should be compiled.

The aforementioned predictions although possible, remain theoretical due to an inherent lack of proof or data of where it was implemented successfully. Some case studies were examined in **Appendix C** where precast concrete was successfully used in the construction of schools, and furthermore in **Chapter 5** some international successes were also discussed, but no examples exist of successful partnering on school projects in South Africa.

In theory though, this proposal is achievable and is subject solely on how innovative the client strives to be in achieving their specific goals. In a socio-economic situation such as the one in South Africa, where large numbers of schools are required quickly and of high quality, the above proposal makes sense.

7.2 Recommendations

The earlier suggested proposal of implementing precast modular construction is innovative and experimental. Therefore, implementing such a system would require certain current models and procedures to be reviewed. The following are recommendations for improvements to certain areas so as to provide for more appropriate circumstances for successful implementation of the suggested proposal discussed earlier.

7.2.1 Public Procurement Model Re-evaluation

Public Works departments would require a restructuring of their current procurement model. A new system, based on the design-build approach, needs to be introduced on all levels. All government personal involved in the public sector construction arena, needs training in the new procurement strategy. Thereby, the various Public Works departments become knowledgeable in this field and can hence compile documents that are clearly defined, fair and suitable. Additionally, this would create an environment where the client understands the risks and principles of the system they are engaging in, allowing the client to be clear on what is required but also understanding how it will fit in with the design-build contract strategy.

7.2.2 Community Education

Communities, for whom the precast school is constructed, might require education and briefing on the product they are receiving. They should be made aware of all the associated benefits such as the cost, time and quality aspects. Furthermore, they should be encouraged to become part of the project and so help their own community and thus create a sense of ownership.

7.2.3 Contractor Education

The Public Works departments should educate potential contractors on the contractual specifics associated with a design-build strategy. The contractor should have enough knowledge in this regard so that tendering and contracting processes adhere to all the norms and standards required by a Public Works compiled design-build regulations.

7.2.4 Development of a South African Database

All projects utilising precast concrete in any manner, should be recorded and stored on a central database for future reference. A database of precast applications would assist project teams in the planning phases of precast modular projects in the future. The following data would be useful:

- Project specifics such as floor area, type of facility, etc.
- Precast elements used
- Project cost including finishes
- Project duration including finishes
- Cost of structural frame
- Construction time of structural frame
- Construction method selected and why
- Procurement method selected and why

7.2.5 Design and Construction Guidance

The SANS 10100:2000 needs to be updated so as to include all the design aspects of precast concrete, since at present it provides very little guidance on the topic. It would remove creative limitation previously placed, due to the lack of guidance, on designers and architects. In addition, precast concrete design should preferably be incorporated in the education and training of any structural design engineer or architect, so that the concept is introduced at an early stage.

7.2.6 Field Test

To prove the validity and credibility of the aforementioned proposal would require an actual 'pilot' project. The client, in this case the Department of Public Works, would need to follow for the most part the guidelines presented by the said proposal. The projects should be well-documented so as to determine reasons for success or failure, and so the strength of the proposal.

7.3 Future Research Suggestions

This thesis examined procurement approaches and after evaluating and identifying the unique traits of each, determined that the design-build strategy is the best suited for a prefabrication approach. To further add to the initial hypothesis, the concepts of Standardisation and Strategic Partnering were introduced. These were only looked at briefly due to these concepts being enormously broad, as a result exceeding the scope of this thesis.

Therefore, to cement the legitimacy of the proposal this dissertation presents, the following fields need additional research:

1. The design-build approach needs to be further analysed. The integrated contract strategy was found to have many variants and these all need examination, along with the contractual implications of each. It is recommended that a study be performed on design-build and all its associated characteristics, including legal ramifications. This concept is vast and would easily substantiate a complete study. The following, amongst others, should be explored:

- Tender preparation and evaluation
- Performance specifications
- Contractual arrangements
- Planning and scheduling issues
- Communication and information distribution constraints

2. The concept of standardisation can be looked at in more detail, specifically how it affects design. The current specifications and construction details of the South African industry can be investigated, so as to potentially determine to what extent they can remain ‘standard’ or to what degrees they can be customised.

3. Most importantly, the concept of strategic partnership needs analysing. This topic is relatively new to the construction arena, and hence a clear and coherent understanding is required for it to be implemented successfully. The risks and contractual implications of this concept need further examination.

Chapter 8

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Appendix A

Extent of Off-site Fabrication for a Multi-Storey Commercial Building

The model example on the next page demonstrates the possible extent of off-site fabrication for a major multi-storey commercial building such as a school, hospital, governmental building, etc. Detailed application will need to be determined for each project (Gibb,1999).

Substructure	Foundations	*Both piled and pad foundations are available as precast concrete elements.*
	Basements	*Precast concrete wall elements may be included. Typically, basement floors tend to be concreted in-situ. However, for multi-basements, especially when the lower slabs are completed after the ground slab, structural steel or prestressed concrete is usually used.*
	Drainage and underground services	*Besides the use of large section (or continuous) pipe lengths, off-site fabrication is not often used.*
Frame	Structural steel	*Structural steel frames, by their nature, incorporate off-site fabrication. In many cases larger sections comprising several individual pieces are pre-assembled, either off-site or at ground level, adjacent to their final position. Extent of pre-assembly will depend upon transportation and craneage opportunities and restrictions. Many steel-framed buildings will use prestressed precast concrete floor units.*
	Reinforced Concrete	*Precast concrete frames are naturally prefabricated offsite. Size and shape of units will depend upon transportation and craneage opportunities and limitations. In-situ concrete frames may use formwork to support the concrete during casting. Steel reinforcement cages may be pre-assembled (normally on-site) and then placed within the concrete formwork.*
Services	Distribution network	*The distribution network for mechanical and electrical services can be pre-assembled off-site. This can include vertical riser sections complete with framing, access platforms and insulation and also multi-service, plug-in modules for horizontal distribution. Sizes and details will depend on the project parameters and access limitations.*
	Plant rooms	*Off-site fabricated plant rooms have been used effectively on many projects, especially where they can be located on the roof of the building.*
Internal Works	Ceiling and floors	*Most commercial buildings incorporate off-site fabricated systems for suspended ceilings and raised access floors. The component sizes are usually fairly small but still facilitate very rapid site installation.*
	Partitions	*'Permanent' partitions may be constructed using traditional concrete blockwork, or more frequently a metal frame and gypsum board walling system. Various off-site fabricated partition systems, usually with posts and panels, are used where relocatability is desirable.*
Facilities	Washrooms and lifts	*Most of the facilities provided by commercial developers can be assembled off-site. Office washrooms and elevator/lift shafts are typical. These are usually areas of high value and complex construction and therefore gain greatest benefit from off-site fabrication.*

Appendix B

Interviews and Correspondence

The following persons were interviewed (only interviews and e-mail correspondence are displayed in this Appendix):

- HA Lewis
  - *Chief Director: Physical Resources, Western Cape Education Department.*

- Gerrie Willemse
  - *Chief Engineer, Department of Transport and Public Works, Western Cape*

Date: 9/03/2012

H.A. Lewis

Company: Western Cape Education Department
Profile: Chief Director: Physical Resources
E-mail: Archie.Lewis@pgwc.gov.za
Address:
Sanlam Office
Golden Acre
22nd Floor

Question 1: **What are the current methods used by the Department of Education in the selection of areas which require schools?**

Department of Education has people who constantly monitor:

- The accommodation capacity of schools
- The demographic of population, especially the migration of learners.
- New housing development (bear in mind that not every new house produces a new learner)
- Immigration from other provinces.

There are 8 education district offices that monitor the conditions and requirements of learners and schools. A constant chain of feedback happens between the district offices and the Head Office in Cape Town. The District Directors at each office decide whether an area qualifies for the development of a new school or whether an existing school needs upgrading/expansion.

Question 2: **What are the requirements of an area for it to be considered for the construction of a school?**

There is a greater demand for High Schools than primary or Pre-primary Schools due to the legacy of the Apartheid era. During this era, people of colour seldom finished high school and normally left with only standard 6 or 8 (Grade 8 and 10). Therefore, high schools were not built as frequently. Today, in the new dispensation, people of colour have equal opportunities in the job market and the demand for high schools is increasing, hence the department of Education needs to build more high schools. Continuous assessment is necessary when the department evaluates whether it is more cost-effective to remodel a primary school into a high school than to build a high school from scratch.

The staff from the district offices will determine whether a primary school is not being used to its full potential and whether the learners can be relocated elsewhere so that the school can be transformed into a high school.

Question 3: **What is the Department of Education's view on alternative building methods?**

Modular units (Mobile units) are currently used to provide temporary solutions for classrooms while construction continues on the school premises. In some cases, administration difficulties can mean that these temporary units stay for a year and even more in some cases.

Question 4: **Any knowledge of alternative methods used or currently being utilised?**

Most schools in the province were built and are still built using conventional brick and mortar methods. This is time consuming (average 14 months) and the Department of Education is currently assessing proposals for an alternative method to act as a 'pilot' for future projects.

Extra Comments

Mr Lewis also mentioned the mind-set of the communities. Some communities feel that alternative building methods are inferior to conventional brick-and-mortar. In well-established communities are brick-and-mortar buildings and alternative material are perceived as inferior (apartheid era provisioning). It must be borne in mind that all demands for new school is in your traditional coloured and black suburbs. He states that the onus is hence on the Department itself to change this perception and not the responsibility of the Contractor/Service provider.

He also mentions that the extent of the development and construction of school facilities is limited by the available budget that the Minister of Finance adjudicates each fiscal year.

Date: 25/11/2011

Gerrie Willemse

Company: Western Cape
Profile: Chief Engineer
E-mail: Gerrie.Willemse@pgwc.gov.za
Address:
9 Dorp Street
Department of Transport and Public Works Offices
5th Floor
Cape Town

Question 1: **What are the current procurement procedures for schools in South Africa, especially with regards to tender procedure, choice of consultants, contractor selection and budget?**

Consultants are listed on a 'Roster' whereby a consultant declares his availability, abilities and specialities. The Department of Public Works (DPW) evaluates the company according to certain pre-set criteria in which the consultant with the most 'points' is awarded the tender. A tender procedure is considered for future implementation.

Contractors, who are required to be CIDB registered, are awarded a project in the traditional manner, whereby a tender is submitted based on drawings from the architect. A in-house QS compiles a separate Bill so as to provide the DPW with a point of reference.

Budget is determined by the National treasury to the Department of Education, where after they then allocate a certain amount to the DPW.

Question 2: **What are the current building methods for schools in South Africa?**

Most schools are built using the traditional method of Brick and Mortar. All buildings have to adhere to certain 'Norms and Standards' which are supplied via Annexures A – I to the project team, describing in addition the scope and approximate costs.

Question 3: **What are the requirements for implementing local labour?**

Contractors are expected to source 50% of their unskilled labour from the local community. A Client Liaison Officer is appointed from the community which is responsible for sourcing the unskilled labour. The Contractor and Client Liaison Officer work in tandem.

The DPW is also under the impression that precast usage implicates job-loss.

Question 4: **What are the chances of changing the current procurement process?**

There is a high probability of changing the current system, especially towards design-build systems. The new approach needs to be motivated and advantages such as time, cost and quality made clear. The DPW suffers from being ill-informed.

The new system requires inspection and should be clearly regarded as certified for use. An ‘Agrément’ Certificate is compulsory.

Appendix C

Case Studies of Precast Applications for School Construction

The following sections present four examples where precast concrete was utilised successfully in the construction of schools. These examples are all international as a comprehensive overview of a South African example could not be obtained. The reasons for choosing precast concrete; design; construction; and procurement characteristics of each case study are discussed. The case studies considered are the following:

1. **Josiah Quincy Upper School.**
   - Modular precast concrete elements were used to deliver a complete school in 108 days (Endicott, 2000) (Smith et al., 2000).
2. **Elk Grove High School**
   - Both structural precast, prestressed concrete and architectural precast concrete members were used very effectively to build a two-story, 3070 m² swimming pool facility (PCI Project Study, 2006).
3. **John Perryn Primary School**
   - A precast concrete panel wall and hollow-core slab system was used for the rapid construction of a two-storey 420 pupil primary school (Buchan Concrete Solutions, 2011).
4. **Lincoln Southwest and Lincoln North Star High Schools**
   - Designers used precast insulated sandwich wall panels, hollow-core flooring, and precast concrete columns and beams to rapidly construct two similar 35 000 m² high schools (Endicott, 2003).

All of the case studies claimed substantial time savings, but more interestingly is that all of the projects had design and construction work in parallel, resulting in an integrated procurement approach where innovation flourished.

Case Study 1

Josiah Quincy Upper School

Boston, Massachusetts, United States

Figure C.1 - Josiah Quincy Upper School after completion and occupancy (Smith et al., 2000).

Overview

The Boston Massachusetts School District commissioned the Josiah Quincy Upper School as a design-build project to facilitate creative solutions and rapid project delivery. The project team delivered the $1.35 million (R12 million) building in 108 days from contract signing to completion by using modular precast concrete elements. By combining a tightly integrated design team, along with a well-considered scheme, the project was delivered and satisfied the budget and time constraints.

Reasons for Choosing a Precast Solution

Construction or expansion of schools is often constrained to the summer recess period so that the school year is not disrupted by construction activity. Some school districts turn to pre-manufactured trailers (similar to mobile homes) to rapidly provide additional classroom space for the students, but many have been dissatisfied with trailers as an option for classrooms due mainly to the fact that lightweight construction trailers do not provide the security and sound lessening characteristics that are commonly desirable in school buildings. The design-build team provided a proposal for the building, which was both competitively priced and addressed many of the shortcomings of the competing trailer system. It also offered a very rapid implementation scheme as compared to conventionally framed, non-precast concrete construction.

Design

The foundation is comprised of conventional wood piles, pile caps and grade beams. The building superstructure, including the floor slab, is comprised of 30 modular precast concrete rings. The rings are four-sided, i.e., they form the walls, the roof and the floor of the building. The rings are placed in contact directly adjacent to one another **(Figure C.2)**. The rings, after painting, form the finished interior and exterior surface of the building which further helps to speed construction. The rings were placed in an arrangement, which forms a central hallway between 24 of the rings. Six other rings form the administrative area of the building. The roof of the hallway is comprised of precast concrete slabs.

A second story was planned and due to the floor and the roof being structurally similar, the excess structural capacity of the roof side of the rings provided the opportunity to readily add a second story to the building in a later phase without significant structural modification of the rings. The second story was constructed by installing precast concrete wall panels directly on the rings which form the first story. No additional floor framing was necessary. The roof was comprised of hollow-core concrete slabs.

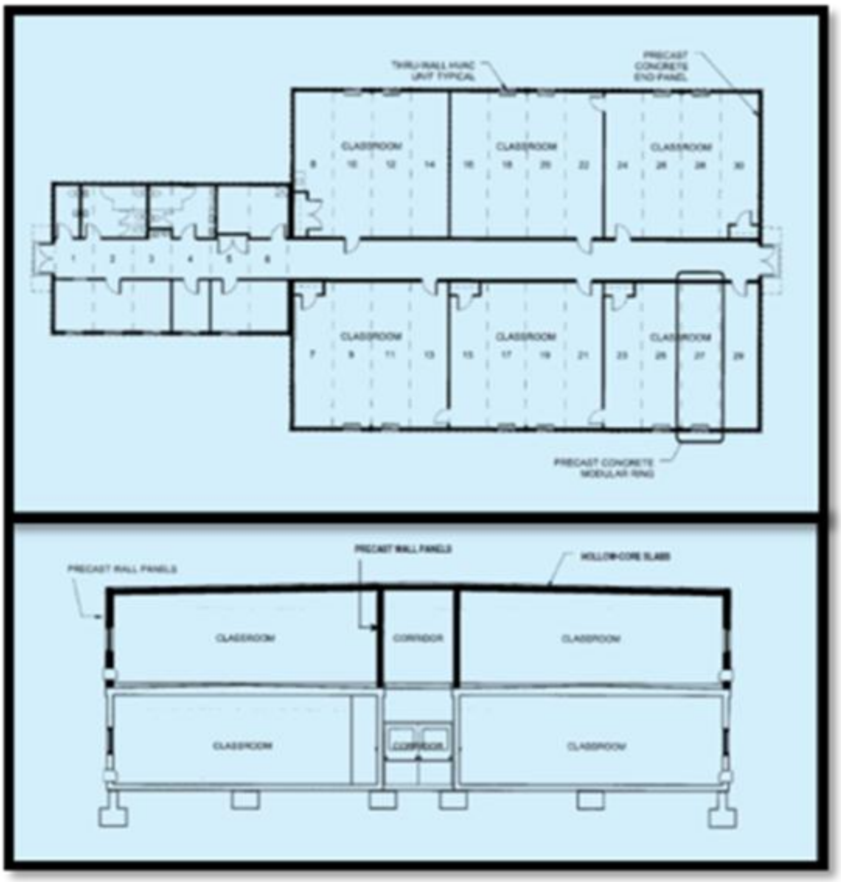

Figure C.2 - Top: Floor Plan of the first phase (first floor); Bottom: Building section through classroom portion (Smith et al., 2000).

Construction

The Boston Public Schools awarded the $1.35 million (R12.15 million) project to the design-build team on May 24, 1999. Approximately 60 per cent of the project budget was comprised of the precast concrete elements of the project. Because the precast concrete rings were variants of other designs, the specific design for this project was quickly executed which allowed fabrication to begin almost immediately. By mid-July 1999, the foundation and grade beams had been completed and the first third of the rings (the administrative area) had been erected **(Figure C.3)**. All of the precast concrete components were erected by August 1, 1999. The rest of the work, i.e., roofing, interior fit-out, doors, windows, and other systems were completed from August to September 9, 1999, when the project was finished. Just 108 days had elapsed since the contract was awarded to the design-build team.

The rings were cast on their sides in the plant, and shipped to the site on their sides in trucks specially configured for hauling precast concrete rings. Because of the dense urban site, the street needed to be closed for a crane to pick the components from the truck and then rotate and place them at the installation locations.

Figure C.3 - Erection of a precast concrete modular ring for the classroom section (Smith et al., 2000).

Procurement

Conventional construction offers the most obvious solution, but it doesn't offer immediacy. A typical project in the Massachusetts district begins with a request for proposal from the architect, with a design contract awarded after bids are received. The architect then draws the plans and submits them for approval along with an estimate of costs. All competing school districts in the state then submit their proposed projects to the state in a competitive bid for state funding. Massachusetts officials select approximately 20 projects that they deem most worthy and award funding. Then open bidding for the contract is conducted. Only when that contract is finally awarded can the project begin (Endicott, 2000).

In the case of the Quincy school, however, the lengthy process was avoided by taking advantage of the state's design-build option. Under that option, the team's bid to both design and build the structure lead to a significant short-cutting of the time line. Design proceeded as site work began, and the two functions ran parallel to the end of the job. By teaming up, the project team was able to put the project on the fast track and for a school district interested in speed and timing, this gave an advantage over a system where each would've been done separately.

Case Study 2

Elk Grove High School

Elk Grove, Chicago, Illinois, United States

Figure C.4 - Exterior of the Elk Grove High School Natatorium (PCI Project Study, 2006).

Overview

Both structural precast, prestressed concrete and architectural precast concrete members were used effectively to build an attractive, two-story, 3070 m^2 swimming pool facility for a well-known high school in a northwest suburb of Chicago. For this project, quick assembly of the precast concrete components facilitated a fast turnaround time that accommodated the owner's tight schedule and realized significant cost savings. Precast/prestressed concrete construction made these scheduling and cost benefits possible. The facility was completed and ready for the upcoming school year—on time and within budget.

Reasons for Choosing a Precast Solution

A significant functional and structural advantage of precast concrete is that it allows long-span construction. In this particular project, single prestressed concrete tee beams spanning 35 m were used. Because of this scheme, thinner walls could be used and fewer support beams were needed. The end result was a spacious interior with unobstructed views of the swimming pool.

The visual advantages of precast concrete were threefold for this project:

- The primary advantage was the creation of a seamless visual unity between the natatorium addition and the high school. The external face and structural material is buff coloured, and the vertical precast concrete panels matched the existing brick high school;

- Another visual advantage was an overall attractive appearance achieved through the use of different treatments and elements. The architectural precast concrete panels of the natatorium features sandblasted and light acid-etched treatment with decorative reveals. Precast concrete columns between windows lend a "monumental" appearance while permitting natural light from the glass curtain walls to flood into the open space; and
- Precast concrete also provided a strong visual advantage within the building. It achieved a smooth, clean, aesthetic appearance that enhanced the interior of the natatorium.

In addition to its visual benefits, precast concrete possesses another important advantage, namely, the ability to withstand the corrosive, high-chlorine environment of a swimming pool facility. Because of its composition, precast concrete is highly resistant to chlorides, so it provides long-lasting durability.

Design

The structural precast, prestressed concrete components comprised twenty single tees, 1.8 × 1.5 m, spanning a clear distance of 35 m.

The architectural precast concrete components comprised:

- Thirty-two panels: 3.7 m × 11 m × 305 mm
- Eight columns: 640 mm × 760 mm with a height of 11 m
- Seven beams: 610 mm × 305 mm, spanning 2.8 m

Both insulated and non-insulated architectural precast concrete panels were used.

Construction

The structural and architectural precast concrete components were manufactured at a plant in Burlington. Precast concrete components were shipped by truck trailer to the project site—a distance of approximately 240 km. The precast manufacturer was responsible for both the transportation and erection of the precast concrete products. Design of the project began in May 2003. Fabrication of the precast products took place in October and November 2003, and erection of the building followed in December 2003. The facility was opened in August 2004, in time for the fall swimming programs.

The total price of the project was $6,8 million (R62 million), while the total price of the precast concrete package was $750 000 (R6,7 million).

Procurement

Township High School District 214 (the owner) turned to an architectural firm to design the facility. The decision was made to use structural precast, prestressed concrete for the main frame of the building and architectural precast concrete for the building's shell. The precast manufacturer worked almost from the beginning of the project with the design team. During the course of the project, the precast manufacturer contributed several cost-saving ideas. Assisting the precast manufacturer was the precast specialty engineer, which provided engineering services, including the shop drawings for the precast portion of the project.

Figure C.5 - Interior of the Elk Grove High School Natatorium (PCI Project Study, 2006).

Case Study 3

John Perryn Primary School

Acton, North London, United Kingdom

Figure C.6 - Front Approach to the School Entrance (Buchan Concrete Solutions, 2011).

Overview

A precast concrete panel wall and hollowcore slab system was used for the rapid construction of a two-storey 420 pupil primary school and a Sure Start children's centre under the UK Governments Primary Capital Programme Initiative, designed to improve the standard of the country's primary schools. Phased construction ensured that the school remained fully functional throughout the site-works. The prefabricated concrete panel system was fast and economical, and reduced programme time and waste without jeopardising future internal flexibility. The precast frame was constructed in just 35 working days (7 weeks) on-site.

Reasons for Choosing a Precast Solution

Precast concrete was chosen for its fire resistance, flexibility, high quality (eliminating finishing trades) and instant working platform. Solid concrete walls and exposed ceiling soffits provides thermal mass for the building which was enhanced by the use of night-time cooling, cross ventilation and high levels of day lighting. The building design achieved a 33 per cent reduction in CO^2 over the current building regulations requirements. 90 per cent of the demolished school building was also recycled or reused on site.

In addition, the following was deemed important when the decision was made to precast:

- The safety risks needed to be minimised in constructing a new building a few meters from a live school environment and a live railway line.
- Waste and costs wanted to be reduced
- The number of deliveries to site and associated traffic, noise pollution, safety risks etc. which is especially important in such a built up area as Acton had to be reduced.
- The project required hurried construction, enabling the school to be delivered in accordance with program constraints, which is vital to school construction.

Design and Construction

The precast manufacturer involved supplied and erected 177 precast concrete units for external and internal walls, stairs, landings and beams – a total of 426m^3 - plus hollow-core floor slabs. Precast panels were up to 14 tonnes, 190mm thick and 4m high were made in a range of lengths and delivered on a just-in-time basis.

Figure C.7 - On-site during construction (Buchan Concrete Solutions, 2011).

The design of the school required flexibility and was facilitated through the use of precast portal frames for the school structure. These were 6.5 metres long and some 3.6 metres in height, being delivered and installed as a single unit. Running at right angles to the main corridor at ground and first floor level, the portal frames, along with the 150mm thick outside walls and 180mm thick cross walls, carry the hollowcore floor units. The panels were lowered into position and carefully aligned with the aid of lasers, before the holding down bolts were finally tightened and the series of wire loops set into adjoining ends were spliced with a reinforcing bar and grouted. The solidity of this solution not only offers aesthetic benefits but also contributes significantly to the airtightness of the building. A total of 479 units were erected by a 10-man erection team at an average of 16 units (equivalent to $125m^2$) per day during the erection period, with a reduction of one week on the contract programme.

Procurement

Little information was available on the procurement route used, but a partnering approach was indeed taken wherein the main contractor, architect and the precast manufacturer worked together in designing, developing and eventually constructing the building.

Case Study 4

Lincoln Southwest and Lincoln Northstar High Schools

Lincoln, Nebraska, United States

Figure C.8 - The Lincoln North Star High School (Endicott, 2003).

Overview

Designers used precast insulated sandwich wall panels to rapidly construct two similar 34 000 m^2 high schools.

Reasons for Choosing a Precast Solution

The rapidly expanding teen demographic in Nebraska's capital city necessitated two new 1,500-student buildings to alleviate the situation. The city authorities requested the creation of two new schools that would last for a minimum of 80 years without major renovation and with minimum maintenance requirements, at the same time meeting a strict schedule.

To meet those needs, the project team designed two high schools that were virtually identical in design. They featured all-precast structural systems and exterior façades clad primarily in precast concrete insulated sandwich wall panels, which provided a number of benefits in appearance, speed and maintenance. The most immediate concern was the schedule, which called for the first of the new schools, dubbed Lincoln Southwest, to open for the 2002-03 school year — just 21 months from the ground breaking. The second facility, Lincoln North Star, was to open for the next school year.

To meet the strict deadlines and to match the 80-year life-cycle requirement, the architects turned to precast, prestressed concrete panels for both schools. The schools also included hollowcore flooring and precast concrete columns and beams.

Design

The project's exterior wall panels were cast with 7.5 cm interior and exterior concrete faces sandwiched around 10 cm of insulation to create a 25 cm-thick panel. Interior walls for one hallway and the school gym of each building consist of 20 cm-thick solid concrete panels. The exterior panels features thin brick cast into the bottom 3.3 metre. On the upper 6 metre of each panel, a lightly sandblasted, buff-coloured finish was created with reveals cast in to simulate limestone blocks.

The two schools are virtually identical except for the entryways — the North Star entrance is rectangular, rather than circular. This allowed the precast manufacturer to use the same casting beds for the North Star school as for the Southwest school. This saved money and sped up the process further.

Construction

The precast components were produced in a plant in Omaha and then trucked to the site, where they were erected by crane. There were no particular erection problems since both sites afforded plenty of space in which to manoeuvre. No further information was available on the construction process.

Figure C.9 - Early phase of the construction at Lincoln Southwest (Endicott, 2003).

Procurement

The team, which included the architect, general contractor, the precast manufacturer and city officials, met on a nearly weekly basis during the design phase. A unique design solution aided the fast-track nature of the projects. Various architects were assigned by the principal architect to design various features of the building. For instance, one designer worked on the gymnasium and locker facilities, while others created the auditorium and still others worked on the food service area. This sped up the design process significantly.

The schedule was aided further by awarding the contract for the precast panels to the precast manufacturer even before complete drawings were finished. The project team felt it important on this type of aggressive schedule to bring everybody on board as early as possible. The team was assembled as soon as possible while preliminary designs were completed. This enabled ample input from all concerned parties so that the job could proceed as quickly as possible.

END OF THESIS