# VERSATILITY AND ADAPTABILITY OF PRECAST CONCRETE BUILDINGS

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## ABSTRACT

*Obsolescence is one of the most common yet least understood issues facing the build environment. Obsolete buildings no longer meet the functional requirements of owners and are often demolished before the end of their usable life. This practice can have a negative impact on economic, social, and environmental sustainability. Adaptability is a primary strategy for mitigating obsolescence, and precast concrete structures have many properties that are inherently adaptable. This is recognized in PCI's Discover High Performance Precast campaign. Versatility, a concept directly related to adaptability, is one of the pillars of the campaign. This paper discusses the many benefits of high performance precast concrete that make it an ideal material for adaptable design. In particular, precast structures are assessed relative to sixteen different strategies for creating adaptable buildings. These enablers of adaptability were identified through a previous literature review conducted by the authors. Through comparisons with these enablers, the adaptability of precast concrete is highlighted and recommendations are made for advancing precast concrete to even greater levels of adaptability.*

**Keywords:** High Performance, adaptability, versatility, obsolescence

## INTRODUCTION

Obsolescence occurs when an object, often still fully functional, is no longer used because its services are out of date or unneeded[1]. This concept, when applied to buildings, is one of the greatest concerns facing today's built environment. Obsolete buildings are often demolished even while they are still structurally sound; many owners decide that it would be simpler to start with a new building, customized to their desired use, rather than to try to change an existing building to match their needs. A 2003 study of building demolitions in Minneapolis revealed that obsolescence was the culprit in approximately 60% of demolitions[2]. This trend leads to wasted resources. As discussed in this paper however, there are methods to combat the obsolescence of buildings.

Adaptability, in the context of buildings, is defined as the ease with which buildings can be physically modified, deconstructed, refurbished, reconfigured, and/or repurposed[3]. Adaptability is the key to mitigating obsolescence. It allows for the modification and extended service life of buildings that would otherwise be demolished due to obsolescence. For adaptability to be most effective it must be incorporated from the initial stages of design. Rather than designing buildings for a fixed set of demands, an adaptable building is designed with an understanding it will change throughout its service life[4]. Measures are put into the design that allow for easy adaptation, thus making it fiscally and/or logistically viable to preserve and adapt rather than demolish. Adaptable buildings offer many benefits and can contribute to economic, environmental, and social sustainability[5].

As defined by the U.S. Government[6], a high performance structure is one which “integrates and optimizes on a lifecycle basis all major high performance attributes.” According to PCI, high performance precast concrete is inherently capable of creating such buildings through its versatility, efficiency, and resilience[7]. Precast concrete be created into virtually any aesthetic appeal. It also allows for structural versatility. Pretensioned members can be both lighter and stronger than reinforced concrete members, meaning that fewer members are required for a structure. Because of potentially longer spans, precast allows versatility in placement of columns and bearing walls. Precast concrete systems can contribute to both space and energy efficiency and can reduce impact on the surrounding environment. Finally high performance precast concrete is a resilient material; it can be designed to withstand multi-hazards (storm, earthquake, blasts) and maintain a long service life[7].

General strategies for creating adaptable buildings -called enablers- have been widely reported; however, there is a dearth of information linking these adaptability enablers to precast concrete buildings. This paper explores characteristics of the precast industry and precast buildings which are inherently adaptable. In particular, this paper:

- Introduces sixteen different enablers of adaptable buildings;
- Describes the benefits of precast concrete with respect to each enabler; and
- Recommends areas where precast systems and the precast industry can enhance potential for adaptability.

## ADAPTABILITY ENABLERS

Adaptability *enablers* are those strategies, practices, processes, and conditions that facilitate adaptation. Eleven design-based adaptability enablers (Table 2) and five process-based enablers (Table 3) were identified during a literature review previously conducted by the authors. Design-based enablers are manipulations to the design that increase the potential for adaptability. These are enablers that are within the control of building designers. Process-based enablers are characteristics of design, supply, construction, and operation systems that increase the systems' abilities to adapt and accommodate change. These enablers do not relate the actual design, but relate to events and processes that occur during design and/or over the building lifecycle. Process-based enablers, such as increasing interaction between the designers, owners, and the supply chain, can lead to new ways of delivering adaptable buildings.

The subsequent sections of this paper discuss each enabler in the context of precast concrete. These discussions are meant as a primer to introduce adaptability concepts at a high level. A more comprehensive discussion of enablers and an expanded list of references can be found in the aforementioned paper from the authors[3].

Table 2: Design Based Enablers of Adaptability[3]

(Words in **bold** are shorthand labels for enablers)

| |
|---|
| **Layer**ing of building elements to allow maintenance, adaptation, or replacement with minimized effect on other elements |
| Accurate as-built **plans**, models, and documentation |
| **Reserve** capacity in the structure and/or foundation (technically a robust design strategy, although often listed as an adaptability enabler) |
| **Modular**/interchangeable components, connections, and layouts |
| Design for deconstruction (**DfD**) and provide deconstruction plans |
| **Simple** framing systems (e.g. larger but fewer members, repeating layouts and grids) |
| **Common** component sizes and details throughout |
| **Access** for assessment and replacement of component |
| Durable, non-toxic **materials** that can be reused |
| Mechanical **connections** that allow components to be readily disassembled |
| **Open** floor plans that are free of structural, mechanical, and other obstructions |

Table 3: Process-Based Enablers of Building Adaptability[3]

(Words in **bold** are shorthand labels for enablers)

| |
|---|
| Early and active involvement of **owners** in planning process |
| **Feedback** channels for designers to learn from previous works |
| **Integration** of supply chain and design team |
| Supply chain can **adjust** to changing requirements over building lifecycle |
| **Codes** and standards that reward adaptability |

## DESIGN-BASED ENABLERS

### LAYERING

Building components and systems are modified and replaced at varying rates. The elements of a building can be reduced to six main categories: stuff, space plan, services, skin, structure, and site[4]. The lifespan of these elements ranges from one-day for stuff to eternity for site (Figure 1). By physically and functionally separating elements into different categories, maintenance, adaptation, and replacement can occur with minimal effects on the other elements in the system.

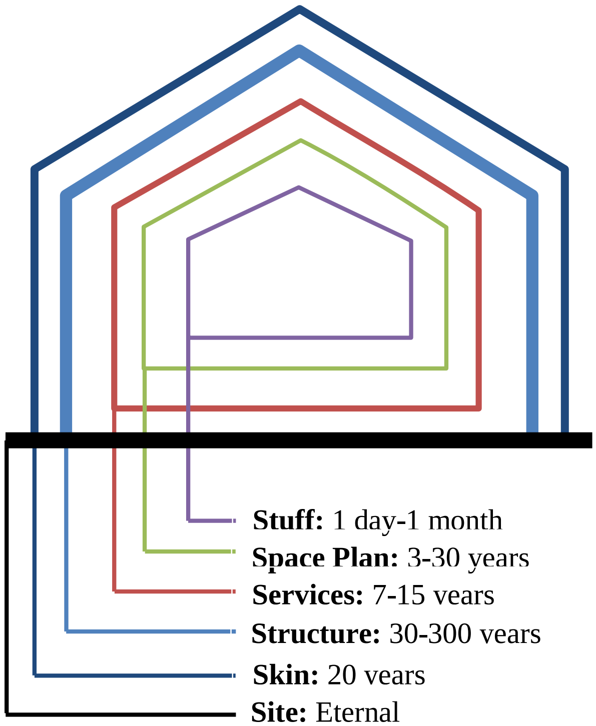


Fig 1. Variable Age of Building Layers (After Brand[4])

By facilitating shallower floor systems, precast-pretensioned members can allow space for building services to be placed outside of the structural members. This allows for services to be replaced and maintained without affecting the structural system. When services must be integrated within precast systems, access points (see “access”) should be provided.

In some precast systems the structure and skin are integrated into wall panels. On one level this works against the layering concept; however, perhaps more importantly, precast walls are incredibly durable and provide a solid location for anchoring new facades or adding other new “skin” as fashions and functional needs change.

Open floor plans, another enabler (discussed later), is a special case of the layer enabler. Pretensioning allows longer spans which can separate the building structure from internal building features. For example, a clear span double-tee roof allows building interiors to be free of structure and open for adaptation to the services, space plan, and stuff layers.

## PLANS

Clear and accurate information on the as-built and current state of a building minimizes uncertainties of a remodel and adaptation projects. Designers are able to make appropriate decisions based on plans, models, photographs, material test reports, maintenance records and any other documentation[4].

Because of the importance of the locations of the strands within pretensioned concrete, it is critical to keep accurate plans of each member. This information is documented on shop tickets. Because precast concrete is cast in a plant, quality control and material testing are well documented. Shop tickets and material test reports provide a comprehensive package of information which will significantly reduce uncertainty associated with any building modifications. It is important that this information is transferred from fabricator to owner to any new owners through the lifespan of the building to minimize uncertainty in the future caused by lack of information.

## RESERVE

As the functionality of a building adapts the design loads may change. Structures can be designed from the initial stages with a reserve capacity so that they are able to support possible load changes to individual members or the entire structure[9]. Reserve capacity can also be beneficial when an adaptation project requires a building to comply with modern codes. In such cases structures with reserve capacity are less likely to require retrofit in order to be code compliant. Reserve capacity is also beneficial when building services are modified and the locations and/or size of equipment changes.

It can be challenging to employ this enabler when dealing with pretensioned members. To satisfy serviceability criteria prestressed members are designed based on expected load. It is not advisable to prestress members for loads that they may never experience. The premise of designing for adaptability is that future changes are difficult to predict, and that designs should be able to handle a range of possible changes. One approach is to prestress members based on given design loads while also providing non-stressed strands or other reinforcement to carry ultimate loads that may be applied in the future. Another approach is to provide members that are large enough to support a range of service stress levels.

Providing reserve capacity in precast members that are not prestensioned is straight forward; members can be sized for serviceability and strength requirements associated with higher load levels. Providing reserve capacity in pretensioned and non-prestressed structures will lead to higher initial costs. For this reason it is critical that owners be involved early in the project (see “owners” enabler) to navigate the balance between adaptability and initial cost.

## MODULAR

Modularity is the creation of a building system from standardized and interchangeable subcomponents[10]. The subcomponents can be rearranged to create different building configurations. Modular components with short life spans can be removed, revitalized, and reused in other projects.

The modular enabler is most effective when applied to those layers of the building that change at the fastest rates. However, modularity can also play a role in the structural layer. Because of standardization within the precast industry, modularity is natural. Precast concrete buildings are created in module form and then assembled on site, with the pieces fitting together using standardized connections. It is possible to design the modules and connections so that they can be swapped and/or configured in alternate ways.

In one example of the modularity of precast concrete, an entire jail was constructed with each individual cell being a module created off site. These modules were then repeated, in rows and in columns being connected by crane until the entire jail was completed[11]. Similar concepts could also be applied to enable adaptability.

## SIMPLE

Simplicity within a building structure can be accomplished through the use of fewer members (and thus fewer connections) and through the use of repeated layouts and grids. A simple layout makes it easier to understand load paths which can assist designers when designing any future changes[12]. Relative to other structural systems, pretensioning facilitates longer spans and/or greater member spacing. This means that simple buildings can be designed to have fewer but stronger precast members.

## COMMON

Commonality involves using standard component sizes and construction details throughout the entire building. Repetition allows for any replacement and adaptation schemes to be applied throughout and also allows for stockpiling of replacement components[13].

Commonality and standardization are hallmarks of the precast industry. Using common member sizes lowers the first cost of a building and can also benefit future adaptability. Although replacement of structural members does not occur at the same rate as other building components (see “layering”), commonality can allow for stockpiling of components for critical connections such as those that are designed for replacement after extreme load events.

## ACCESS

Building elements that are likely to wear out and need replacement should be easily accessed, and access points can be designed into a building. This allows for regular assessment, maintenance, and replacement to be performed on specific systems (e.g. electrical, plumbing) without damaging any adjacent systems. Access should also be provided for assessing elements such as electrical fuses or structural members that are designed to absorb damage in extreme events[14].

In some precast buildings, particularly for industrial occupancy, buildings systems are exposed. Exposed HVAC, electrical, and plumbing allows for easy assessment without causing any damage to other components. Access can also be provided for assessing critical structural elements following extreme load events.  When designing access points, the type of evaluation should be considered.  Visual inspections may require a different degree of access than evaluation using non-destructive evaluation equipment.  The same access provided for assessment can also be designed to facilitate removal and replacement of critical elements (see “DfD” enabler).

## MATERIALS

Building components that are long lasting have potential for reuse.  For a component be reused it is important that it is made from both durable and non-toxic materials. The material must be durable enough to outlive the functional life the building it is housed in and maintain capacity for use in another project[12]. Toxic materials such as asbestos are not good candidates for reuse.  Additionally, toxic materials are expensive to remove and can discourage owners from remodeling existing buildings.

Precast concrete is a durable material that can be designed to withstand extreme weather, military level blast, earthquake, as well as any ordinary day-to-day wear. Because of its durability precast concrete it is ideal for promoting adaptability, both in remodel/repurpose projects and in deconstruct/reuse projects. When adaptations require removal of individual members, the durability of precast members increased their potential to be reused on a different project. Also, concrete is a non-toxic material which also makes it a good candidate for reuse.

Other properties of concrete, including precast concrete, contribute to adaptability. Concrete has high thermal mass which helps buildings maintain comfortable and uniform temperatures.  This can allow for a reduction in the energy use of the building, contributing to the high performance of the structure.  Thermal massing is a passive feature that is less likely to be affected by changes in building services technology.  Conejos et al.[15] notes that buildings with high performing services are likely candidates for adaptation.

CONNECTIONS

Connections between different elements within a structure should be designed to allow for easy removal and replacement of components as needed. Connections should not deter from the reusability of the components, such as drilling holes or coating with difficult to remove adhesives[16]. Bolts are typically better than welds for encouraging adaptability.

For precast members, it is possible to use bolted connections which facilitate component removal and replacement. Mechanical splice mechanisms, such as those used for precast concrete piles, can also be utilized to connect precast building members. Figure 2 shows a method for connecting precast concrete members that utilizes a bolt and plate system. Should an owner decide to remove the components shown in the figure, the connections could be removed by simply unfastening the bolt. This does not cause any damage to the members and would allow for the components to be installed at another location in the same condition as when it was removed. To maximize the adaptability of this connection, openings for the bolts should be left ungrouted.

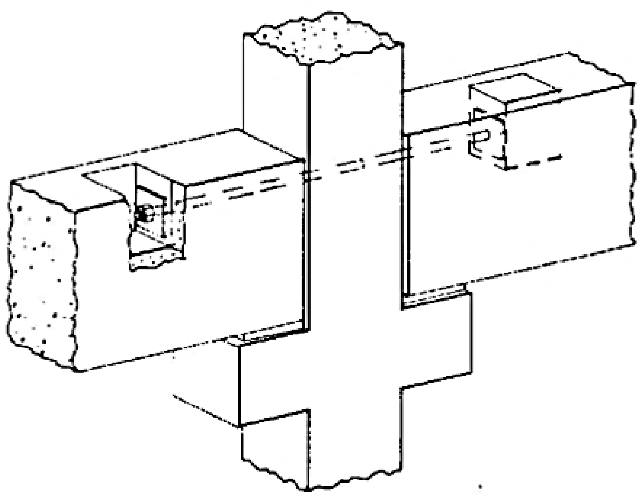

Figure 2 – Precast concrete beam-to-column removable connection[17]

OPEN

Keeping the floor plan open and free of structural, mechanical, and other obstructions, makes it possible to adapt the space easily to a desired function. This is especially important in rental spaces where each tenant may be interested in a unique layout[18]. The open floor plan allows for the adaptations to occur at the stuff, space, and services layers.

The nature of pretensioned concrete allows for longer beam spans than many other structural systems making it easier to create open floor plans. The increase in span means that fewer supporting columns are necessary, so it is possible to reduce the obstructions and concentrate structural elements at the exterior walls of the building.

## DESIGN FOR DECONSTRUCTION (DfD)

DfD involves creating a plan for the end life of the building as part of initial design. The end of life plan describes the methods for the removal, reuse, and/or disposal of various components in a system that will result in a low environmental impact and in monetary recovery by the building owner.

DfD focuses on the sequence and load path both during construction and deconstruction. It is important that the building elements can be removed without being damaged and without damaging any of the other elements. DfD has been described as a design philosophy separate from adaptability[19]; however deconstruction and adaptability both rely on enablers such as layering of building systems and use of mechanical connections.
Because precast members are typically constructed offsite and then transported to the building site, they include features that can also be leveraged for DfD. Lifting hoops, tie down points, and transportable sizes can all contribute to DfD and reuse. Recycling, another facet of DfD, is generally less desirable than reuse but is preferable to scrapping of building materials. Concrete and steel, the primary materials in precast systems can both be recycled.

In one example of a deconstruction project, an entire apartment building in the Netherlands was deconstructed and the components reused to build a single family dwelling. The project, located in, involved the reuse and renovation of six apartment buildings. Plans dictated that a sand grout be used to connect the various precast concrete members. The contractor planned to disassemble the components at the location of the sand grout; however the grout was much stronger grout than had been intended, and deconstruction resulted in partial damage to the components as well as additional expense[8]. In spite of these complications, the precast members were still successfully reused for the single family dwelling.

Deconstruction has also been utilized in the United States. The Centennial Olympic stadium in Atlanta, GA was designed to become the Braves stadium after the Olympics in 1996. Some of the seat units were removed during the stadium transition and were then reused to build two high school stadiums[20].

## PROCESS-BASED ENABLERS

### OWNER

Because of their financial stake in a building, owners have paramount ability to affect adaptability[21]. Thus early involvement from owners is critical. Adaptability can be included as a topic in initial planning meetings allowing owners to decide features that would best contribute to the function of the building and that will facilitate future adaptation.
Adaptability also can be leveraged as a marketing tool by building designers and suppliers; describing a project or system as adaptable can engage interest and support from potential owners.

Precast fabricators are in a good position to implement this enabler because they are often involved with owners early in projects. Additionally, the approach of precast fabricators to produce building systems – rather than just components – presents an opportunity for fabricators and owners to integrate adaptability at a holistic level.

## FEEDBACK

Buildings are constantly evolving based on current trends and owner needs; they are started but are never finished[4]. By returning to previous projects, designers and suppliers can learn how owners have adapted buildings. When reviewing previous works, the following questions should be asked: What types of adaptations are owners requiring? What could have been done during initial design to make these adaptations easier? What lessons-learned can be applied to future designs? By adopting this mindset, designers can learn from their previous works and apply that knowledge to future projects.

Precast fabricators can benefit from visits to previously completed projects. There is always something that can be gained from learning how owners adapt and personalize their buildings. Precast buildings, just as buildings of any material, are constantly changing over time so revisiting them can provide designers and fabricators with lessons learned and thereby improve the adaptability of future projects.

## INTEGRATION

The process of creating adaptability falls within the domain of designers, contractors, suppliers, operations personnel, owners, and occupants. The more integrated these parties are the greater the opportunity for adaptation[22]. The precast industry is already highly integrated; often designers, fabricators, and erectors work within the same company. This integration can lead to a streamlined delivery of adaptable building projects.

## ADJUST

Supply companies are most effective at facilitating adaptability when they can adjust to changing economic, technical, and social conditions[22]. Adapting a building often requires a supply of replacement parts, particularly for elements that are routinely replaced (see "Layering" enabler). Suppliers that can quickly fabricate or that stockpile parts can contribute to adaptability. Suppliers that do not remain in business or that discontinue products lines can hinder adaptability. In short, suppliers must be committed and able to support their product lines even as technology, construction trends, and owner requirements are continually changing.

As a part of the 'structure' layer precast concrete elements are not routinely replaced; however, the precast industry can still contribute by supporting maintenance and extended life precast structures. The Maintenance Manual for Precast Parking Structures[23] is a good example of how the industry can support the entire life of precast buildings.

It is also important that supply chains can adsorb, confirm quality, and distribute reused and recycled building components and materials. The ability of supply chains to adjust is critical because reused components and recycled materials can vary in size, quality, quantity, and geographic location. The precast industry could work towards standards and guidelines in support of a niche market on QA/QC and resale of reused precast concrete element. Creating a closed-loop supply chain is a worthy challenge for the construction industry and one that can have positive impact on sustainability[12].

CODES

Codes and standards are the driving force in many design decisions and industry trends. For example, development of "green" building standards such as the USGBC LEED program[23] have significantly altered how designers, contractors, and owners talk about and value their buildings[24]. Codes, standards, and legislation promoting adaptability could have similar effect on industry practices[25]. As evidenced by the discussions in this paper, the precast industry is well-positioned to benefit from such codes, standards and/or legislation.

## PATH DEPENDANCE OTHER CONSIDERATIONS

Adaptability is about making present decisions in such a way that those decisions do not limit future decisions. In other words, adaptability mitigates *path dependence*. Precast parking structures are one example of path dependence. Often parking structures are designed so the entire interior is sloped in a continuous ramp from base to top floor. This type of design is useful for parking garages; however sloped floors tend to limit functional use to parking. If parking is no longer desired, the sloped floors create a challenge for building reuse. A more adaptable approach is to design a flat floor structure and placing ramps on the exterior of the garage. In keeping each of the floors level, it is easier for the building to be adapted to different functions after the parking structure is no longer desired. In this situation, the ramps located on the exterior can be removed using DfD concepts.

This idea for a parking structure shows one way that ingenuity of design creates the potential for the adaptation. This doesn't mean that external ramps are always the best approach for parking structures; such decisions must be made on a case-by-case basis. By focusing on adaptability from the beginning stages of the project, designers and owners can select building features and designs that limit path dependence and allow for many different types of adaptation and use. The key is in making present decisions that expand future possibilities.

Additionally, when designing a building for future reuse and adaptability, it is also important to consider which adaptability characteristics will have the largest effect on the overall environmental impact the structure. In one study [27] the environmental benefits of reusing different elements of a precast structure were evaluated. The study found that the benefits of reusing beams and columns were almost negligible compared to the significantly larger benefits of reusing floor slabs. This study showed that it is possible for owners to focus on specific components for reuse, rather than the entire structure, and still maintain a reduced environmental impact. By focusing on adaptability of individual components (e.g. the floor slabs), it may become a more manageable step for owners to consider adaptability in their projects.

## SUMMARY AND CONSLUSIONS

In this paper sixteen enablers of adaptability were introduced and discussed in the context of precast concrete buildings. The enablers were further divided into design-based and process-based enablers. These enablers of adaptability can mitigate obsolesce within the built environment, an issue that often leads to demolition of buildings prior to the end of their usable life. Versatility, one of the pillars of PCI's High Performance Concrete campaign, speaks to how adaptability can be affected precast concrete systems. The precast industry is well positioned to offer adaptable buildings that are resistant to obsolescence.

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