Adaptive efficiencies: Responding to change through anticipatory prefabricated design

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ABSTRACT: Pedagogically, the study of architecture often revolves around the creation of new, program-specific designs. In practice, buildings are newly constructed and occupied based on their intended program use without forethought. As requirements change, buildings go through series of modifications. When modifications are no longer feasible, buildings are often demolished or left vacant. In an effort to combat this one-time-use mentality, *Adaptive Efficiencies* offers an architectural system that adapts to a building's differing physical and programmatic requirements through the use of prefabricated, deconstructable panels, or *Fins*.

The programmatic and physical lifespans of urban buildings are influenced by two major factors. First, the vacancy rate of commercial spaces remains the highest of the sectors within the real estate market each year as the supply continues to outweigh the demand and tenants move elsewhere, leaving owners without prospective replacements (Molony 2012b). Concurrently, residential spaces continue to be in high demand (Molony 2012b). It seems as if one issue could present a solution for the other, yet in many cases, the vacant building is demolished and a new structure is erected in its place.

Rather than demolish, choosing to reuse buildings decreases the environmental impacts and energy use associated with building construction (*The Greenest Building* 2011). Yet the current methodology of adaptive reuse poses only momentary solutions. Eventually, the reused building encounters the same problem with which it started: vacancy, no longer needed for its intended program use. A widely accepted architectural methodology has yet to be developed that anticipates future reuse.

By employing design flexibilities within the context of adaptive reuse and reconstruction, one could essentially design for more than just a building's second use. The proposed *Fin System* is devised with material efficiency and disassembly in mind so that a building may adapt to a new program use each time the demand changes. Taking advantage of standard material dimensions, the *System* includes a series of wall panels in nominal dimensions that reduces the production of material waste during construction. These panels, built with mechanical fasteners for increased ease of disassembly, can be transported from floor to floor by using a standard service elevator, eliminating the need for a crane. Standardized installation of a prefabricated kit of parts allows for design flexibility within a framework that provides a new use for a building, decreases the amount of material waste in demolition and construction, and offers a new program for an outdated space.

The design study demonstrated an application of the prefabricated *Fin System* and its construction methodology through the adaptive reuse of the office space of 1851 South Bell Street in Crystal City, VA. The following illustrates the benefit of adaptive reuse over demolition to satisfy the need for residential space in Crystal City. The achieved outcome of the research and design of the *Fin System* when combined with various passive strategies created a material-, water- and energy-efficient building.

KEYWORDS: Prefabrication, Adaptive Reuse, Deconstruction, Efficient, Fin System

INTRODUCTION

In order to combat waste produced during building demolition, it must be understood how building typologies *live* and what factors influence their lifespan. Many times, building vacancy is a major source of demolition incentives and so vacancy patterns must be identified. Although multiple strategies for building reuse have been practiced over the years, a methodological approach to reuse is not yet entrenched within architectural practice. The following case study seeks to identify a feasible alternative to demolition through the research of flexible and efficient building initiatives, and the study of building lifecycle and vacancy values.

1.0 OFFICE BUILDING VACANCY

Of the sectors within today's real estate market, the office sector continues to report the highest vacancy rate each year; hovering around 17 percent compared to the multifamily residential sector's 4 percent (Molony 2012b). In the late 1980's, office building stock rose in most large American cities as these buildings were being constructed while the demand faded (Kohn and Katz 2002). Today, "[a]s market conditions evolve, residential values are continuing to improve while offices are becoming more expensive to maintain and have ever shorter life cycles" (Challis 2011, 2).

1.1. Demolition

Not only will reuse help to solve a programmatic imbalance, but it will also reduce the rate of material waste created by demolition within the construction industry. For, "although it represents about 8% of gross domestic product (GPD) in the USA, the construction sector consumes 40% of all extracted materials, produces one-third of the total landfill waste stream, and accounts for 30% of national energy consumption for its operation" (Kibert, Sendzimir, and Guy 2002, 6). There is great potential for adaptive reuse projects to reduce negative social, economic, and environmental impacts at a local and global scale. However, demolition seems to remain the preferred approach within the non-residential sector as shown by the decreasing service life of buildings. In a survey of 105 non-residential buildings, 47 fell within the 26-50 age class (O'Connor 2004, 2). The adaptive reuse of a building can prevent the materials of a demolition project from entering the waste stream (*Estimating 2003: Building-Related: Construction and Demolition Material Amounts* 2009).

2.0 CHALLENGES AND FEASIBILTY OF ADAPTIVE REUSE

Buildings are designed around program-specific requirements that can, in some cases, hinder the viability of an adaptive reuse project. Categorical feasibility factors of adaptive reuse include: structure, exterior finishes, physical design components affecting daylighting, service systems, interior finishes and code regulations.

While structural material degradation may be commonly assumed to directly dictate the service life of buildings, the results of a 2004 North American building service life survey states that in reality, only 3.5% of building demolition was determined by structural failure (O'Connor 2004). Therefore, with a building's structural capacity still functional, the next potential issue to address is the structure's ability to handle the live and dead loads of the new program. The structure of an office building is designed by code to handle greater live loads than residential buildings (*International Code Council 2012*). Therefore when reusing an office building for a residential program, the structural member's ability to accept alterations will not have to be taken into consideration.

In order to maximize the value for the land, most projects are built to maximize rentable floor area. In many cases, this involves constructing the thinnest floor plate in combination with the shortest allowable finished floor to ceiling height in order to ensure the maximum number of floors is incorporated into the design. This eliminates the need to analyze the existing building's structural capacity for additional floors during redesign. Another method of maximizing rentable floor space is to design the structural system to accommodate an open floor plan. In order to preserve the building's structural integrity, existing loadbearing walls or exoskeletons must be incorporated or accounted for within the structural system of the reuse design.

Although designing office buildings with the shortest allowable finished floor to ceiling height maximizes rentable floor space, it creates an undesirable ceiling height for residential spaces. While the finished ceiling height of the typical office building built through the early 2000's is 8'6" or 9'0", "there is a current move, led by many of the high-tech firms, to create more democratic, loft-like, technologically advanced work environments, typically with ceiling heights of 12'0"-14'0", " allowing ample height for either program use (Kohn and Katz 2002, 8, 35). Similar to ceiling height, the amount of daylight that enters a room greatly affects the interior environment.

> A daylit room depth should be less than two and a half times the height of the window head to maintain a minimum level of illumination and an even distribution of light (Brown and DeKay 2001, 201).

Strategies for using daylight to light American office buildings were forgotten after World War II, as air conditioning and artificial lighting technology improved. Today, the depth of the floor plate in typical American office buildings seriously impedes natural daylighting abilities as floors often have dimensions of 50 feet from the core to the facade. When reusing an American office building for residential use, it is likely that a courtyard will be carved out of the center of the building in order to both improve daylighting techniques and create a typical floor plate dimension for residential use.

In order to improve an American office building's daylighting performance during its new use, a passive lighting strategy must be incorporated into the design. This will undoubtedly affect the building's mechanical and electrical services designed for the building, which represents another categorical challenge of adaptive reuse projects. Evolving from the private offices of the 1960's, the typical North American office building floor layout is predominantly open today (Kohn and Katz 2002, 5). Adapting the current heating, ventilation and air conditioning systems from either an open floor office or private office layout will require intensive reconfiguration in order to serve each residential unit with individual ductwork. Similarly, the plumbing capacity will need to be adapted from one program to the next, which can be intensive as well. But, in the case of both the HVAC system and the plumbing system, many of the physical fixtures and connections can be reused in the new design. The electrical hardware will be the system likely to produce the most material waste, as the majority of the physical hardware will be replaced by new wireless connections.

As the office hierarchy flattened in the 1980's, the interior finishes and partitions evolved along with the service systems. The typical dropped ceiling found in most office buildings today is designed to conceal ductwork, piping and wiring of these service systems. When removing this ceiling type for security and acoustical privacy reasons in residential applications, the service systems must be reworked within the new design.

Another factor influencing the production of material waste is inseparable from the selection of a material itself. In an effort to reduce first costs, high performance building materials are often traded for a less expensive alternative. But, this exchange could directly affect the material's durability performance, which affects the building's material waste over its lifespan if the less durable material must be replaced. It is possible that the more expensive material is of a higher quality, which would allow it to withstand reuse and therefore offset the initial cost for the material with its long lifespan.

The type connection used in material assemblies greatly affects the material's capacity for reuse. From exterior cladding to interior finishes, each subsequent material choice has a resulting choice of connection. Some materials become less desirable from a reuse standpoint due to the intricacy of their disassembly or their inability to be disassembled. For example, an office building's unitized glass curtain wall is much easier to disassemble and reuse than a concrete mass wall with punch windows.

Restrictions or regulations associated with the International Building Code (IBC) or the National Register of Historic Places (NRHP) can affect the materials incorporated in a building. Fire safety dictates many of the IBC regulations surrounding material types. Concrete construction, found in many Washington DC office buildings, offers multiple benefits as concrete itself is inherently fireproof and can be used to minimize floor-to-floor height where overall building height it limited by code or zoning regulations. While the focus of many IBC regulations center around safety, the intent of the NRHP is to preserve a building's aesthetic qualities that represent local history. Many times, the regulations enforce the preservation of the façade characteristics over the interior design, as it is the most frequently viewed aspect of the design. This restriction could hinder the design of adaptive reuse projects whose strategy for attracting a new tenant type is to use the façade as a way to express its changing program. For this and similar reasons, certain aspects of the codes and other regulatory barriers are relaxed, and tax incentives are proposed in order to promote and increase the speculative profitability of adaptive reuse projects (Kohn and Katz 2002, 149).

While tax incentives or code relaxations attract some interest in adaptive reuse projects, the building industry should not have to rely on incentives as a reward for choosing ecological option. "Buildings currently consume 32% of the world's resources" (*ESD Design Guide* 2007, 04). With the linear product-waste system as the dominant path for the building industry, materials from the "one billion square feet of buildings [that] are demolished and replaced each year" are sent to the landfill rather than saved through reuse (*The Greenest Building* 2011, ix). Not only will this material count toward the carbon footprint of the site, but also the energy embodied in the acts of demolishing the existing building and constructing a new building in its place will count as well. Analysis has found that:

> It takes between 10 to 80 years for a new building that is 30 percent more efficient than an average-performing existing building to overcome, through efficient operations, the negative climate change impacts related to the construction process (*The Greenest Building* 2011, viii).

Although an office building may have outlived its designed function, it has not outlived the useful lifespan of some of its materials and its structure. A Life Cycle Assessment will discredit the argument for the demolition of a building for the construction of even an energy efficient building by showing objective numerical proof that the adaptive reuse of a building will consume less energy and exhaust less carbon during the reuse than the new construction.

3.0. CASE STUDY DESIGN STRATEGIES

Once the preferred building typologies for reclamation and reuse have been chosen, and the challenges of adaptive reuse have been identified, the process of locating potential areas of implementation begins. Additionally, design methodologies and objectives are developed.

3.1. Analysis of abandoned office building stock

As a result of the Department of Defense's (DoD) Base Realignment and Closure (BRAC) recommendations in 2005, Arlington, Virginia lost demand for over 4.2 million square feet of leased office space as of September 15, 2011 (*BRAC Transition Center*).

> Crystal City is most affected with approximately 3.2 million square feet of [the U. S. General Services Administration's] (GSA) holdings in these buildings considered BRAC-impacted DoD space" (*BRAC Impacted Buildings and Leases in Arlington* 2011, 2).

Losing leases with five agencies of the DoD as a result of BRAC, 1851 South Bell Street of Crystal City is a prime candidate for residential conversion with 309,629 square feet of vacant office space since September 2011 (*BRAC Impacted Buildings and Leases in Arlington* 2011, 8).

3.2. Site analysis

Crystal City has benefitted from its proximity to Washington, DC and major transportation hub Reagan National Airport, becoming one of Arlington's largest concentrations of density and jobs (*Crystal City Sector Plan* 2011). But, with the BRAC recommendations, the city is in great need of redevelopment. The current master plan for Crystal City adopted by the Arlington County board in September of 2010, indicates that a mix of uses will help balance the current single-use dominated areas. Figure 1, below, represents current demolition statistics for Arlington County; indicating not only that retail and commercial demolition is on the rise in recent years, but also that there is a greater amount of commercial and retail demolition compared to residential units. Figure 2, below, denotes residential unit to commercial gross floor area ratios, displaying a deficit of residential units in Arlington County. In an effort to increase the urban density of living as well as the life on the street, a mixed-use program shall be incorporated into the design.

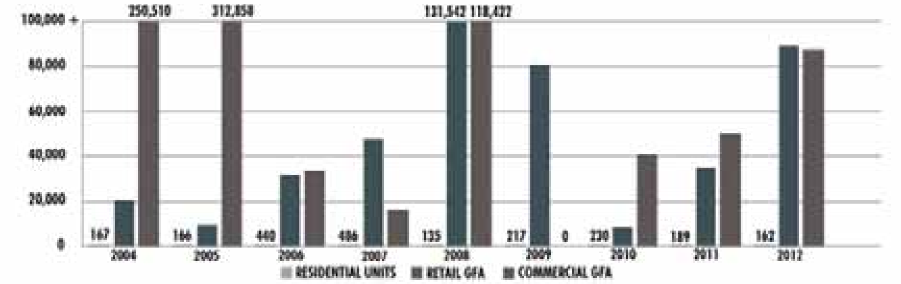

Figure 1: Demolitions in Arlington County, VA. Source: (Graphic: Author 2013, Values: *Arlington, VA Annual Development Highlights* 2004-2012)

Figure 2: Residential unit to commercial gross floor area (GFA) ratio. Source: (Graphic: Author 2013, Values: *Arlington, VA Profile 2013*, *Building Resilience in Boston* 2013, *Boston 2013 Housing Report*, *DC Office Market* 2012, *Demographic and Housing Profiles 2010*)

3.3. Building candidacy and feasibility

Meeting the initial self-imposed criteria for the feasibility of an office to residential conversion, 1851 South Bell Street possesses many qualities that facilitate the conversion process. While the building was built in 1968, it arguably still has 55 years left to stand, assuming its intended maximum lifespan, like other buildings in the developed world, is 100 years (Kibert, Sendzimir and Guy 2002). As an office building, 1851 South Bell Street was designed with the structural capacity, 50-80 PSF, to house the intended mixed-use program requiring 40 PSF. The building height is 198'0", comprised of twelve floors with the majority of ceiling heights around 9'3". 1851 South Bell Street is a stand-alone office building with a short north façade, preferable for passive heating and cooling techniques. The depth of the floor plate, from the façade to the building core, ranges from 40' to 60', requiring two courtyards to be carved out of the building's interior floor plate to allow for better daylighting and more typical residential floor plate dimensions. The column grid throughout the building is 20'x20' and components of the façade are independent from the building's structure. While the capacity of the current utilities requires an update, additional amenities include eight passenger elevators and one freight elevator. A costly addition to any project, these elevators will amply serve all programs on the twelve floors of the building. Furthermore, 1851 South Bell Street's adjacency to the Crystal City metro station will increase its ability to attract tenants.

3.4. Design and construction efficiency initiatives

While there is no deconstruction system in place within the 1960's design of 1851 South Bell Street, in order to account for the potential future use of the building, construction methods should be high priority. The following expresses estimated percentage of material use during demolition and construction depending on the type of construction method employed. When demolishing a building without employing a reuse strategy, *Option 1*, 100% of the building materials are destroyed and will require 100% of the building materials to be replaced during new construction. When choosing to adaptively reuse a building with traditional construction methods, *Option 2*, we can assume that some of the building materials will be destroyed while some will be reused. So, 50% represents material use during both demolition and construction. The way material assemblies are constructed and joined, determines its flexibility and adaptability. When adaptively reusing a building and employing prefabricated and adaptive construction methods that anticipate a building's future reuse, we can assume that some degree of efficiency is achieved. Therefore, a figure of 40% represents material efficiency during construction in *Option 3*.

Another efficiency initiative involves digital fabrication, which allows for detailed, computer-accurate customized fabrication. While digital methods and prefabrication should not drive the design, it can be used as a way to mass-produce a fixed set of customized building components with interchangeable universal connections that allow for residential unit variability. The unit matrix developed in the case study includes two, two-bedroom + den units, eight, two-bedroom units, eight, one-bedroom units, and four, studio units per residential floor (Figure 3). Within that matrix, there are multiple floor layouts per unit type. Just as designers have learned to construct building elements with standardized material dimensions, prefabricated components can be used in a similar scalar manner to form a building. Prefabrication already offsets cost differentials, increases productivity in the warehouse and on-site, and even improves contractors' safety. Additional benefits can be achieved if a system is developed that allows these prefabricated elements to be deconstructed, allowing for adaptive reuse to take place.

Figure 3: Proposed typical residential floor plan. Source: (Author 2013)

Finally, in order to deliver the project in a time-efficient manner, an adaptive reuse project can take advantage of completing the reuse in stages. Tenants can occupy completed sections of the substantially complete project while construction continues in the remaining portions of the building. If residential construction begins on the top floors of the building, and ground floor retail spaces are constructed, the original office space can remain on the lower floors. As the demand for residential space grows, each sequential floor remaining below can be converted into residential units. Similarly, if the demand for commercial space outweighs that of residential space, the conversion effort can cease.

3.5. The *Fin system*

Using material and energy waste reduction as a driver for design decisions, the *Fin System* developed into a design methodology that uses a series of prefabricated panels connected to create *Fins*. Figure 4 depicts the design methodology flow chart for the *Fin System*. Mechanical, electrical and plumbing systems are included in the prefabricated interior wall panels consisting of metal studs and gypsum wall board, called *Fin Wall Panels* (Figure 5). A number of *Fin Wall Panel* types were developed during the case study to accommodate unit location and variability. These types include, a Bathroom-to-bathroom, a Bathroom-to-kitchen, a Kitchen-only, and a Double-bathroom-to-double-kitchen (Figure 6). Installation is standardized and identical regardless of the apartment unit size, which reduces on-site coordination. Screw connections are used to connect *Fin Wall Panels* together to each other, and to the floor and ceiling, to allow for greater ease of disassembly and reuse (Figure 7). Similarly, non-pressurized mechanical and plumbing pipes are connected with gasketed connections, while pressurized pipes are able to be screwed together with the aid of a length of flexible piping (Figure 8).

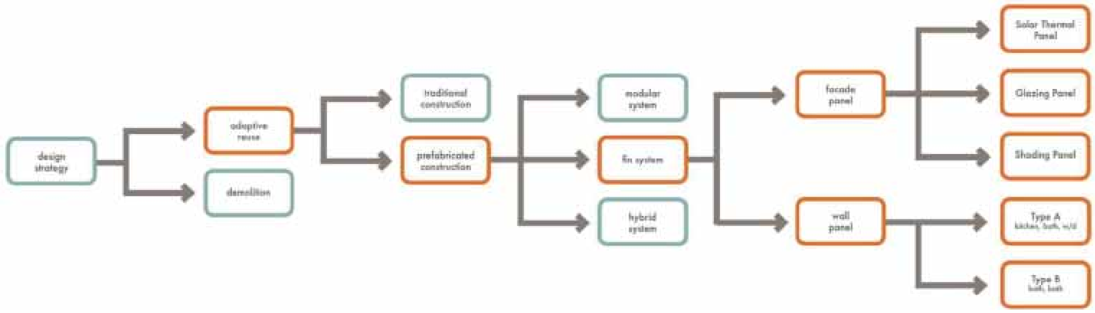

Figure 4: The *Fin System's* design methodology flow chart. Source: (Author 2013)

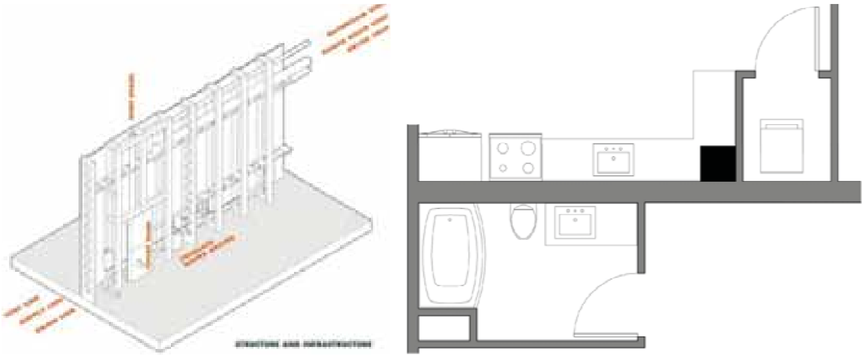

Figure 5: Two, 8-foot Type A *Fin Wall Panels* at a kitchen/bathroom/washer + dryer condition. Source: (Author 2013)

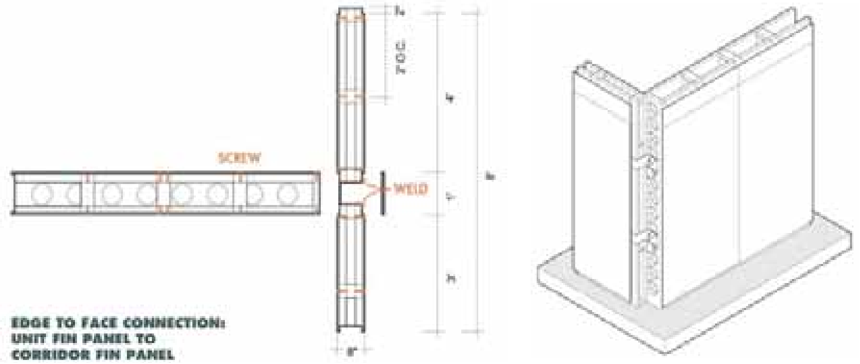

Figure 6: Edge to face *Fin Wall Panel* connection: Unit *Fin Wall Panel* to Corridor *Fin Wall Panel*. Source: (Author 2013)

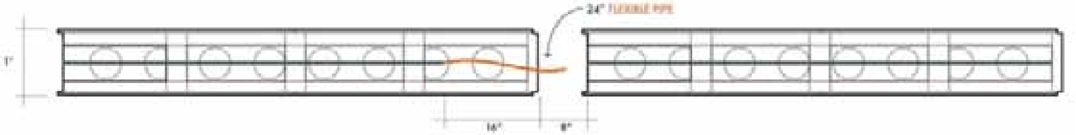

Figure 7: Edge to face *Fin Wall Panel* connection: Unit *Fin Wall Panel* to Corridor *Fin Wall Panel*. Source: (Author 2013)

Additional energy-saving efforts were incorporated into the case study design. In keeping with a paneling methodology, the façade was designed to be a series of solar thermal panels, glazing panels, and louvered shading panels in 2', 4' and 8' sections (Figure 8). Operable louver panels are optimized by orientation to shade the interior and reduce the building's cooling load (Figure 9). Passive evacuated tube (or solar thermal) panels provide supplemental heat for the radiant heating flooring system included in the design (Figure 10). Additionally, the façade panel system is not tied to the interior fin system, allowing for variability in design. Both interior *Fin Wall Panels* and exterior façade panels are designed to stack, which both saves space during transportation from the warehouse, and allows them to fit inside a service elevator, which eliminates the need for a crane during reconstruction.

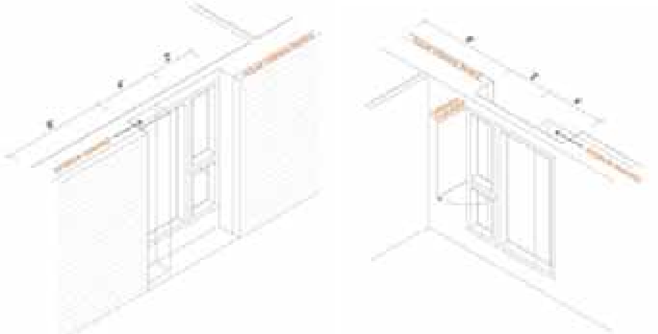

Figure 8: Exterior panelling system axon. Exterior view (left). Interior view (right). Source: (Author 2013)

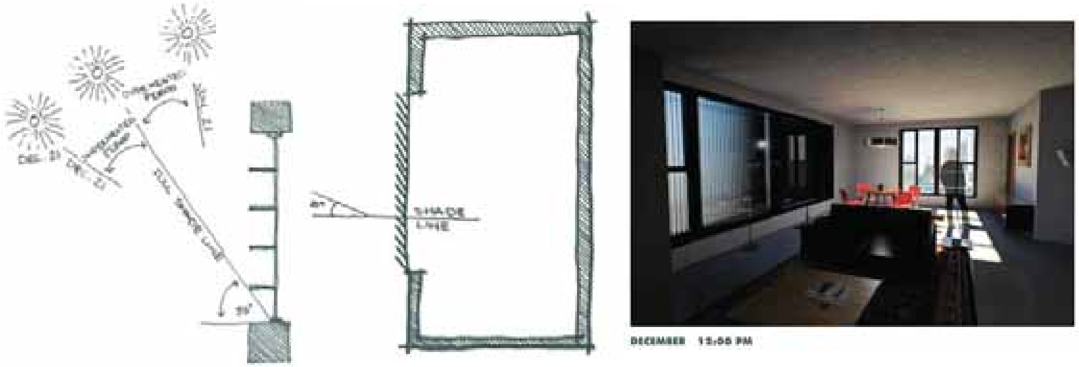

Figure 9: Southern horizontal façade shading orientation diagram (left), Eastern and Western vertical façade shading (right), Rendering of expected daylighting from a SW corner unit in December at 12:00PM. Source: (Author 2013)

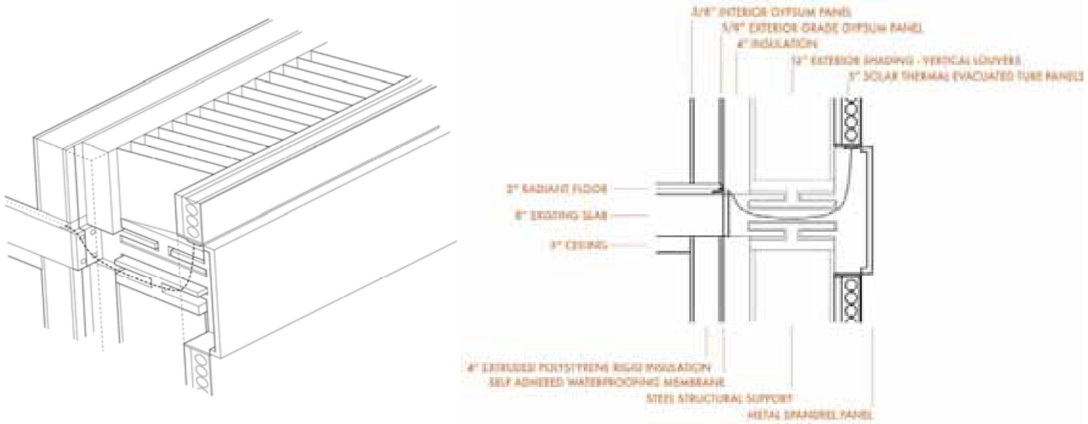

Figure 10: Axon (left) and section (right) of the floor slab to exterior wall assembly detail. Source: (Author 2013)

It is understood that any design decision has an associated consequence. The following decisions are incorporated within the adaptive reuse design: in an effort to save space and material for piping, tankless water heaters installed in the panels replaced the commercial hot water tank. 60% of toilet water supply is supplied by rain water collection, reducing water demand. While additional piping is needed for toilet rain water supply lines, hot water piping lengths are reduced with tank-less water heaters. Replacing existing windows with operable windows and passive shading devices balances the associated burdens of façade reconstruction by reducing the amount of energy needed to cool the building. The associated material and energy burden required to install a radiant flooring system is balanced by the passive evacuated tube façade panels which reduce the energy demand during cold months. Time and material quantities are saved with the installation of prefabricated panels, which lessens the burdens associated with the removal of interior commercial office finishes throughout the building and floor plate for courtyard space. Deconstruction burdens are additionally reduced with disassembly methods incorporated in the *Fin System* design. The decrease in construction costs associated with the elimination of a crane allows for service elevator upgrades, if needed. By using construction cost data from *2010 RSMeans* guides, the rough estimated cost of demolition efforts for 1851 South Bell Street is $3 Million (Mewis 2009). For rough estimation purposes, this simply included the demolition figures for interior wall removal, interior floor finish removal, interior concrete slab removal, and exterior concrete and glass removal. The rough estimated cost of reuse with the proposed design is $7.5 Million (Waier 2009). The rough reuse estimate includes construction figures for interior walls, interior floor finish, exterior glass, exterior metal shading, and exterior wall assemblies. Surely, the numerical and ecological savings combined add value to this proposed methodology for adaptive reuse.

CONCLUSION

With the actual service life of the typical building significantly less than its expected lifespan, the associated amount of waste produced in the construction industry is greater than necessary. Since construction materials comprise three quarters of the nation's raw material use, demolition of buildings without the intent of material reuse creates substantial environmental impacts (*U.S. Material Use Factsheet* 2012, 1). Given that the majority of demolition projects occur due to non-structural motives, it seems that the fashion-driven aspect of architecture has a pronounced negative influence on the building industry's current practice.

Understanding the theories behind humans' settlement patterns and trending cycles of a building's programmatic use, architectural practice may be able to embrace change by incorporating flexible principles into design strategies. By pre-planning, architects can create buildings that adapt as changes occur. Not limited to new construction, these adaptive strategies can be incorporated into the *second-use* of a building to encourage another use in the future. With technological advances facilitating many aspects of architectural practice, including a building's adaptability, it is important to remember the primary functional characteristics of architecture and to achieve that function without excess simply because technology has made it possible. The balance of technology, materiality and functionality within ecological architecture helps create an environmentally conscious product while incorporating cutting-edge efficiency with required performance parameters.

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