The reduction of waste and promotion of user autonomy in architecture through the design and application of adaptable systems

Brian Burnell Walker

Iowa State University

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The reduction of waste and promotion of user autonomy in architecture through the design and application of adaptable systems

by

Brian Burnell Walker

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF ARCHITECTURE

Major: Architecture

Program of Study Committee:
Ulrike Passe, Major Professor
Clare Cardinal-Pett
Fredrick Malven

Iowa State University
Ames, Iowa

2011

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# LIST OF ABBREVIATIONS AND ACRONYMS

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<thead>
<tr>
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<th>Description</th>
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<tbody>
<tr>
<td>AFCI</td>
<td>Arc Fault Circuit Interrupter</td>
</tr>
<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigerating, and Air-Conditioning Engineers</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>C&amp;D</td>
<td>Construction and Demolition</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>FT.</td>
<td>Foot or Feet</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating Venting and Air Conditioning</td>
</tr>
<tr>
<td>IBC</td>
<td>International Building Code</td>
</tr>
<tr>
<td>IECC</td>
<td>International Energy Conservation Code</td>
</tr>
<tr>
<td>IMC</td>
<td>International Mechanical Code</td>
</tr>
<tr>
<td>IFD</td>
<td>Industrial, Flexible, and Demountable</td>
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<tr>
<td>IN.</td>
<td>Inch</td>
</tr>
<tr>
<td>NEC</td>
<td>National Electrical Code</td>
</tr>
<tr>
<td>NL.</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Pcd</td>
<td>Per Capita Per Day</td>
</tr>
<tr>
<td>RCC</td>
<td>Resource Conservation Challenge</td>
</tr>
<tr>
<td>SRI</td>
<td>Sound Reduction Index</td>
</tr>
<tr>
<td>STC</td>
<td>Sound Transmission Class</td>
</tr>
<tr>
<td>UFAD</td>
<td>Under Floor Air Distribution</td>
</tr>
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<td>WWII</td>
<td>World War II</td>
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ABSTRACT

A degree of success in architecture can be attributed to its ability to meet the needs of users. Traditionally, user and market demands are determined through a process of past experience. Both individual users and encompassing demographics are questioned in order to determine current needs and usages. Through this information, architects program and develop the building to meet current needs, and typically establish permanent and fixed solutions without much adaptability. This inability for architectural adaptation becomes a potential issue when user demands and usage practices shift or change, leaving the building design impractical for users or completely obsolete. At this point, building owners have two choices to meet changing user demands, costly remodeling or demolition/rebuild. Countries such as the Netherlands have had an influx in building demolition as post World War II (WWII) building plans, often small and compartmentalized, were no longer desirable for usage. As a result, designers have been developing adaptable architectural structures and spatial infill to allow for future change in order to decrease waste and continue to meet user demands.

Beyond waste prevention and staying abreast to shifting user demands and usages, an adaptable approach to architecture can directly promote user control over their given space and promote user satisfaction. In order to provide user satisfaction within a design, a designer must allow for adaptability by the user, studies show the more adaptable an environment is, the more the user will be satisfied. This thesis outlines the arguments for adaptable design, benefits that are provided, aspects designers must consider, a potential adaptable design system, and the applications of these adaptable designs in an architectural space and market.
CHAPTER 1: INTRODUCTION

(1.1) THE ARCHITECTURAL ISSUES

While designing for current demographic needs can provide adequate buildings in the short term, it can have devastating long-term consequences. Traditional buildings are continually being built to meet current user needs, however the variable factors of everyday life, changing social standards, and evolving functional requirements lead to buildings becoming outdated due to their inflexible and static nature. Because of this, buildings that lack flexibility or adaptability often undergo major renovations or demolition well before the building becomes unserviceable. As a result, traditional building design is responsible for a majority of redundant construction and demolition waste, which increases yearly with exponential construction activity. Because of population and building construction growth, the United States Environmental Protection Agency (EPA) has begun to monitor the waste being produced by Construction and Demolition (C&D) to include renovations. The EPA has targeted C&D for reduction, reuse, and recovery as part of its Resource Conservation Challenge (RCC). The RCC is a national effort to conserve natural resources and energy by managing materials more efficiently. The goals are to prevent pollution, promote recycling, reduce toxic chemicals in products and waste, and conserve resources.

There have been only two EPA reports on C&D waste, 1996 and 2003, providing two comparison points. The EPA’s growing concern with C&D waste is directly connected with the growth in U.S. construction spending (Figure 1). In 1996, the EPA estimated that US construction spending was approximately 600 billion dollars with 135,530,000 tons of C&D waste. This amount of waste translates to 2.8 lbs. of waste per capita per day (pcd). In 2003, however, the EPA estimated construction spending around 900 billion dollars with 170,000,000 tons of C&D waste. This amount of waste translates to 3.2 lbs. pcd, an increase of 0.4 lbs. pcd illustrating C&D waste production increased. Table 1 shows the 2003 C&D waste estimates.
Figure 1: U.S. construction spending in 2003.\textsuperscript{6}

Table 1: Estimated amount of building related C&D in the U.S. in 2003.\textsuperscript{7}

<table>
<thead>
<tr>
<th>Source</th>
<th>Residential</th>
<th>Nonresidential</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Million tons</td>
<td>Million tons</td>
<td>Million tons</td>
</tr>
<tr>
<td>Construction</td>
<td>10</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Renovation</td>
<td>38</td>
<td>33</td>
<td>71</td>
</tr>
<tr>
<td>Demolition</td>
<td>19</td>
<td>65</td>
<td>84</td>
</tr>
<tr>
<td>Totals</td>
<td>67</td>
<td>103</td>
<td>170</td>
</tr>
</tbody>
</table>

*Percent* 39% 61% 100%

\textsuperscript{6}C&D managed on-site should, in theory, be deducted from generation. Quantities managed on-site are unknown.

\textsuperscript{7}Note: Data are rounded to the appropriate significant digits. Data may not add to totals shown.

While the EPA has not provided any recent totals or reports, the prior reports allow for a conservative estimate for total construction waste in 2011. Taking only the construction growth from 1996 to 2003 into consideration and not potential population or waste amount growth, C&D waste for 2011 would be estimated at 209.4 million tons. However, due
mainly to Executive Order 13423 which requires all federal construction, renovation, and demolition projects to achieve a 50% recycling rate where markets or on-site recycling opportunities exist, states have begun regulating C&D waste recovery efforts. While current EPA structure does not allow the agency to determine every states recovery amounts, rather the 2003 report noted eight states and their recovery rates. Of these eight states, an average of 48 percent recovery was obtained. While promising figures, this still leaves room for improvement with 52% or 88.4 million tons of waste still entering landfills in 2003.

As inferred, the main problem is that architects have designed buildings as permanent structures without high regard to adaptability and disassembly. Therefore to alleviate this issue, future building designs should be geared towards continual change and adaptability to prevent the wasting of resources and to meet changing user demands. To continually meet changes with user demands, a space must be adaptable to meet user satisfaction. Well-known architectural writers, such as architectural professor emeritus of the University of Maryland, Guido Francescato, conceive that user satisfaction is dependent upon variable categories. These variables can be understood as: the objective characteristics of the residents, housing environments, and the perception of housing environments. In order to provide user satisfaction within a design, a designer must allow for adaptability by the user, for the more adaptable and directly controlled an environment is, the more users will be satisfied.

Architectural spaces can be best served by using an adaptable approach that encounters a constant change of users such as leasable office and apartment buildings. Not only must these architectural spaces be adaptable to meet potential daily changes from individual users such as creating a larger dining or meeting area for guests or clients, but also meet the needs of a new user whose spatial preferences or needs may be different from the previous user. Approaching architectural adaptability with this in mind, an architect must take into consideration the adaptability of the structure, spatial dividers, and utilities, all of which typically act as spatial constraints. However, if adaptability is within user control to facilitate autonomy, then only spatial dividers and utilities need to be considered. Alterations to architectural structures by untrained individuals can pose great risks to both the building
and its users. In this fashion, the architectural structure can act as the limiting constraint within the design, but also acting to further support the adaptable systems.

(1.2) POTENTIAL APPLICATIONS

While all architectural spaces could benefit from the application of adaptable features, this thesis is focused on leasable spaces within fixed exterior structures. Leasable spaces, either commercial or residential, have constant changes in users and thus constant changes in user needs. Apartment buildings for example, potentially have new occupants every year, each user having a different set of needs and new expectations of the space. Because this thesis work is tailored toward user needs and control within such areas as leasable space, the adaptable features are designed for interior applications only. Another reason to focus on leasable spaces is that building codes must be maintained to protect users, such as the placement of firewalls and meet utility needs. Leasable spaces are separated by firewalls that cannot be altered or moved. With this in mind, it is understandable and practical to be able to alter the interiors of apartments, but not the placement or size of the apartments. Exterior adaptability does have great potential architectural applications, any exterior changes would be required to meet building codes limiting changes to be made by specialized and trained workers. Having a user controlled adaptable interior, a user could lease a space based solely on location and size, and not for its spatial layout. Also users could rearrange their spaces and utilities when needs change or for something different. This thesis work thus focuses on maintaining standard building practices, not only to promote practical application for new buildings, but also for potential to retrofit existing buildings.

(1.3) POTENTIAL BENEFITS

Through adaptable architectural space, user demands can be met by continual change and user control promoting both user autonomy and satisfaction. The implications for such a space could be, but not limited to:
1. **Adaptable building design systems reduce waste in construction, renovation, and demolition.** As the EPA reports have shown, C&D waste is on the rise with waste going into landfills. An adaptable building could help to reduce C&D waste. As adaptable systems proposed here are prefabricated units, less on-site construction is needed. As with any prefabrication, units are manufactured using parts and material sized for specific usage, eliminating most waste in production, increasing efficiency and decreasing cost. On-site construction utilizes non-standardized materials for specific needs and results in construction waste. As the adaptable systems proposed here are also removable, renovation waste is limited to removed systems. Removed systems however could be utilized elsewhere if serviceable, and thus reduce both renovation waste at the initial site, and renovation or construction waste at the second site. As with renovation, demolition waste is reduced as adaptable systems are implemented.

2. **Designers avoid assumptions of spatial usage of interior spaces for non-user specific buildings such as condos, apartments, leasable commercial spaces, general offices, etc...** When designing for specific clients who will be using the buildings, architects and designers can determine the spatial needs by creating a user/client-based design program and implement permanent design solutions to meet clients needs. However, when clients sell or lease the building or space, as such the case for leasable commercial spaces, condos, apartments, general offices, etc… the spatial requirements must be assumed based on current usage trends or left unfinished. If these assumed designs include permanent fixtures, any changes to usage trends or other unforeseen uses will prevent the space from meeting the user demands. By designing adaptable spaces, architects and designers can meet both client and user needs while providing for the potential needs of future users without limiting usage.

3. **Users would be able to adapt their spatial surroundings to meet their daily, and future spatial needs.** Usage of architectural spaces can change daily, so it is
necessary to allow users to change their spaces to meet new needs. For example some occupants may need larger sitting areas on particular occasions such as for parties or meetings, a task that would require more than moving furniture. Users too, much like the buildings architect, cannot be expected to understand the changing spatial needs of their future desires. While interior spaces initially may meet their desires upon occupation, life events, such as a new baby or new employee hires may dictate spatial change. Traditionally this is met by moving to another space, or costly renovation, ideally the currently occupied space could simply adapt to meet new criteria. An ideal space “belongs” to the user, so they should have the freedom to adapt it without causing architectural problems or additional building cost.

4. **An adaptable and user controlled space potentially could result in a lower square-footage floor plan that maintains spatial and comfort needs of the users.** When architectural spaces are designed and built with permanently placed interior walls and utilities, every space has a fixed size and use. However not all spaces are needed simultaneously assuming low occupancy numbers, resulting in spaces not used continuously throughout the day. But if spaces were designed to be adaptable, users could reclaim unused square footage in order to accommodate the spatial requirements of used space. As an example, an apartment user could decrease the size of a bedroom during the daytime hours, allowing for a larger living room space. Since these spaces could share square footage, the overall square footage could be much lower than if both spaces were static.
CHAPTER 2: RESEARCH PRECEDENTS

The concept of architectural adaptability within this thesis focuses on user autonomy and reducing C&D waste. The following research precedent reviews separate aspects of C&D waste reduction from user autonomy, but both include aspects of adaptability. Each section will not only highlight the issues present but also attempts to solve the issue.

(2.1) SPATIAL FLEXIBILITY AND ADAPTABILITY PRECEDENTS

(2.1.1) FLEXIBILITY RESEARCH IN THE NETHERLANDS

While the EPA has highlighted that a high amount of C&D waste created in the United States is due to demolition of buildings from lack of usage, this issue is not limited to this country, but is a worldwide issue. In the Netherlands for example, much research has been invested for adaptable promotion into architecture to combat C&D waste. In the Netherlands, post WWII buildings (1945-1965) are no longer utilized, many of these buildings are being demolished long before the economical and technical lifespan has expired. The main reason being that post WWII buildings were built for the current living and business standards of the time, a standard that no longer meets the present spatial, functional, technical requirement, and amenities no longer meet the needs of building users. Beyond the obvious economic waste, these premature building demolitions have led to material waste and energy consumption. In the Netherlands, total building and demolition waste is about 22 million tons per year, of which 5 to 6 million tons are ‘produced’ in the construction phase. Currently, the Dutch non-residential building sector has a surplus of these dysfunctional office buildings with approximately 68 million square feet unoccupied, which is roughly 15% of the total building stock. The reason for this low occupancy, is that companies prefer more up-to-date communication services, more open floor plans, and updated building appearance.
Many Dutch researchers have sought to prevent future building dysfunctions by producing flexibility for the building users. Even as far back as the 1960’s, N. John Habraken observed that the static Dutch building practices would not provide sustainable buildings for potential future usage. Habraken developed a theory to increase building functionality by emphasizing the importance of flexibility-in-use. This theory states that buildings are divided into two parts: support and infill. The support of a building is represented by the buildings structure and is seen as rigid. The infill on the other hand represents the remaining building components, such as the façade, utilities, interior spacing and furniture, which are all to be considered flexible. The Habraken theory has continued further development and elaboration ever since, providing the basis for numerous projects by the 1970’s. Projects as Ommoord in Rotterdam (NL), Molenvliet in Papendrecht (NL), and Keyenburg in Rotterdam (NL) allowed researchers and designers to evaluate the theory in practice. However, it was not until 1999 that the lack of long-term functionality of Dutch building stock received broader attention when a fund was established by the Dutch government, known as Industrial, Flexible, and Demountable (IFD) program, to stimulate institutions and contractors to develop flexible solutions for future buildings. The major aspects of IFD technology are:

• Focus on industrial construction or prefabrication to produce less waste during off-site production and allow for waste recycling.
• Prevent waste from occurring on space limited building sites.
• Design for dry building construction methods, meaning that the building is built in pieces off-site and assembled on-site.
• Focus on flexible or adaptable designs that allow buildings to be “changeable.”
• Allow the building to be demountable, meaning that during future renovation or demolition, the building can be disassembled and materials reused or recycle.

While the Dutch government-backed IFD program ended in 2004, it produced approximately 90 projects with diverse solutions for practical and/or project-oriented problems. Internationally the program gained recognition as it stimulated researchers to
implement similar strategies into the building practices of other countries, including the United States, Japan, Finland, and the United Kingdom. The residential building sectors especially saw strategies developed and several projects were built, such as Next21 (Japan)\textsuperscript{15} and SATO PlusHome (Finland)\textsuperscript{16}. These projects and research was to achieve increased functionality and lifespan of the buildings by flexible implementation on the infill-level. Many of these projects and designs could not stand the test of time due to rapidly changing user demands and building regulations, giving rise to the idea that architecture not only needs to be flexible but also adaptable to survive changing needs.

THE FLEXIBLE BREAKTHROUGH PROJECT

One project from the Netherlands and IFD was ‘Flexible Breakthrough’. The basic principle of Flexible Breakthrough was to maintain already existing building stock and structurally renovate in order to minimize waste. As the name suggests, Flexible Breakthrough adhered to its basic principle by demolishing one of the four bearing walls in each apartment and replacing it with steel supported framing. The interior spaces would double in size, meeting current spatial requirements of users, while amenities and utilities would be also updated. However, because one of the four bearing walls has to be demolished part of the floor slab was also removed. As a result of demolition it was not possible to apply all the principles of IFD-technology. After the installation of the new steel-supporting frame, the floor slabs needed to be reconnected using concrete. The project boasted that this method would hold specific advantages over new construction, which include:

- Substantial reduction of waste, due to less demolition and application of IFD-technology.
- Better possibilities for building improvement with respect to acoustical properties, quality, and flexibility of building services.
- Complete demolition and new construction would cost per house about €27,000 (approximately $31,000).
- Faster availability of apartments for rent.
To back up the claims, a full-scale prototype test was carried out on a Dutch apartment building that was slated for demolition. The results not only prevented undesired waste, but the removal of the bearing wall elements through an opening in the roof required four times less labor than conventional demolition. Beyond demolition, the installation of four floors of steel frame took only half a day of work, while the connection of the concrete floor to the steel beam proved to be simple, load worthy, and cost effective (Figure 2). In conclusion this reconstruction proved to be 15% less expensive than a potential complete demolition and new construction on the basis of an equally physical quality building. Waste savings for this renovation type would be a case-by-case basis but proportional to the building size, as without renovation the entire building may have been demolished.

Figure 2: Image after the removal of load bearing wall (left). Image after installation of steel supporting frame (right).

So far several research projects have been performed on aspects such as façade concepts and the integration of building services. In 2004 a full-scale model of one of the building services concepts had been built and tested in the FAGO laboratory at the Technical University of Eindhoven. The housing corporations involved in the demolition test studied the possibility of a demonstration project. In this project eight apartments will be renovated.
according the Flexible Breakthrough project. There is also interest from some East European countries to apply the concept to existing apartment buildings.

THE IFD TODAY PROJECT

Another potential solution from the Netherlands and IFD project was IFD Today. Unlike Flexible Breakthrough, IFD Today supported the demolition of buildings to their foundations and constructing new buildings on top of the old foundation with IFD technology. IFD Today believed that the floor system played a key role in the building concept, and in order to achieve a fully flexible and adaptable spatial floor plan, the floor elements would have to span from façade to façade. As the majority of the post-war apartment blocks have only four floors and no elevators, this approach would make it possible to construct a building with six floors with an elevator. This addition of space and accessibility adds to the buildings economic feasibility, while the floor plan of roughly 10 x 100 meters enables modular, free partitioning. Several research projects have been executed integrating building services, vibration reduction of floor systems, façade systems, and component adaptability. Currently university students are developing research proposals to further examine the adaptability and functionality by occupying the prototype building.

THE SLIMBOUWEN STRATEGY

One of the forerunners in architectural flexibility and adaptability field is at the Technical University of Eindhoven in the Netherlands. Current research teams conclude that flexibility and loss of functionally have been an integrative issue for researchers for at least four decades. They believe when flexibility is implemented in the infill only, the structure of the building acts as a limitation to flexibility-in-use, therefore leads to a lower level of functionality. If flexibility is applied to the infill and the building support, a satisfactory level of flexibility may be achieved. Researchers at the Technical University of Eindhoven are developed a design strategy to anticipate the potential future of dysfunctional buildings, the Slimbouwen® strategy. It has been developed to tackle social and environmental
problems that are a byproduct of the building industry including waste, energy consumption, and CO₂ emissions. The goal beyond adaptable buildings is to provide flexibility and comfort while reducing waste by creating a more efficient building.

As of 2011, Slimbouwen® has yet to be commercially realized, however research has shown that a physically adaptable building leads to a higher level of flexibility compared to often used design strategies. So far, Slimbouwen® adaption techniques can be implemented, such as replacing columns within a predefined zone to expand internal usage. Other methods include breakthroughs of existing non-load bearing walls, and multi-use spaces. The next step for the Slimbouwen® team is to approach the building process in a practicable way to develop products on a component level. Once practical solutions are designed, market research and building tests must be applied along with fine-tuning. Overall, the flexibility potential and adaptable building design strategies are backed by Slimbouwen® as the solution to many current issues.

(2.1.2) MEROFORM MODULAR SYSTEMS

While the MeroForm has specifically been tailored toward interior and temporary exhibition structures and forms, the system provides an example of architectural adaptability. An offshoot of MERO Systems Group of Germany, a recognized leader in steel and aluminum architectural structures, MeroForm Systems offers an extensive range of modular systems. The MeroForm System can be configured in an infinite number of forms while maintaining an ease of construction, system strength, and durability. The adaptability is achieved through the use of easily assembled tubes and nodes only limited by the space and user’s imagination. In essence, each node is spherical and acts as the connection or pass through point for multiple tubes. An example of the MeroForm M12 is shown in Figure 3. The MeroForm M12 tube/node system was born by developing a simple yet versatile modular exhibition construction system modeled on principles occurring in nature.
By using the M12 tubes and nodes traditional geometric and biomorphic shapes be formed. While the tubes and nodes form the structural elements, MeroForm Systems can be clad by a multitude of materials utilizing M12 panel connectors or spider connectors seen in figure 4. If clear plastic clips or plastic fixing channels are used the frame remains visible. Alternatively, the structure can be completely hidden. The Cladding Connector M12 was designed to position lightweight exhibition panels up to 16 mm in front of the space frame. The new M12 Half Node may be used to reduce the distance between structures and cladding panels. This method of fixing provides a stable connection between the nodes of the space frame. Cladding can be manufactured from readily available proprietary panel materials and vacuum formed plastic panels. For open-air environments special waterproof fabric membranes can be provided.
(2.2) USER AUTONOMY AND CONTROL PRECEDENTS

(2.2.1) BUCKMINSTER FULLER

Richard Buckminster Fuller, American engineer, inventor, designer, and futurist, was an influential figure during the first half of the 20th century. As a technical advisor to the magazine *Fortune* from 1938-1940, Fuller had a special talent for visualizing patterns and trends for future public needs. By the late 20’s, Fuller observed architecture was heading toward a fixed utility grid, which could potentially be a problem as people would become disconnected with the amount of natural resources used. His early architectural work on the Dymaxion house in 1929 provided a “modern” solution to autonomous utility and resource usage in urban dwellings. But in 1945, Fuller redesigned outside utility resources that were sought by free users. Fuller reworked the Dymaxion design in 1945 to move from simple living to responsible living, both freeing the user from outsourced resources and making them responsible for producing and maintaining their own resources. Beyond being designed as a kit of parts assembled on site, the Dymaxion house represents the first conscious modern attempt for an autonomous building, completely self-sufficient and regulated by its users. Fuller understood resources were finite and controlled by suppliers. The Dymaxion design
fought to reduce resource usage to address utility needs and personal environmental responsibility by including elements such as a “fogger” shower, packaging toilet, and a vacuum turbine for electric power. While Fuller only developed one prototype of this design (Figure 5), his adoption of techniques and technology initiated rethinking of utility support in architecture.

Figure 5: Fuller's Dymaxion house prototype.

While Fuller’s Dymaxion house design focused on resource saving technology, this approach required removing the utility aspect from the larger grid. The aspect of utility is placed on the designer and user, and thus the application of autonomy or self-governance. But another important feature in Fuller’s design was the attention to both pre-manufactured parts and standard construction methods. This added to the building’s autonomy by being assembled by users and not constraining the house to a particular site. But while this approach to an “autonomous” building addresses both initial site and resource autonomy, it does little to address the issue of spatial autonomy once built.

(2.2.2) ARCHIGRAM

Archigram was an avant-garde architectural group formed in the 1960’s based in London. The group’s approach to design was based on futurist, anti-heroic, and pro-consumerist ideals, drawing inspiration from technology to design new realities through
purely conceptual projects\textsuperscript{19}. The group committed to a “high tech” and lightweight infrastructural approach focusing on survival technology. The group began to experiment with modular technology to create conceptual autonomy for buildings and cities by applying the idea of mobility through the environment, space capsules and mass-consumer imagery. The following projects exemplify two of Archigram’s concepts that harbor architectural site autonomy.\textsuperscript{20}

**PLUG IN CITY**

Designed by Archigram’s Peter Cook in 1964, the Plug-in-City concept expressed an unprecedented level of spatial location control. Conceptually, the Plug-in-City is represented as a mega-structure that in and of itself is not a building, but a massive framework continually constructed upon by self-guided machines with utility grid hookups (Figure 6). Once the structural and utility framework was established, dwellings could be introduced in the form of either cells or series of slotted standard components. Archigram’s design allows users multiple access points and the advantage of cheaper dwellings that can be separated from the structural framework and utility connection of buildings.\textsuperscript{21}

![Figure 6: Archigram's Plug-in-City. Peter Cook, 1963.](image-url)
THE WALKING CITY

Designed by Archigram’s Ron Herron in 1964, the Walking City concept expressed architectural autonomy through the concept of movable buildings. The Walking City would consist of a network of “intelligent” buildings or robots that carry self contained living pods capable of roaming either cities or countryside (Figure 7). The concept was derived from a combination of insect and machine, and a literal interpretation of Corbusier’s aphorism of a house as a living machine. These living pods could be independent but also parasitic, as they could “plug in” to localized stations to either exchange occupants or replenish resources. In need or want situations, the individual pods could link up, forming an actual Walking City, able to grow or shrink as needed. Citizens who would reside in the Walking City are nomads, able to live comfortably in their own homes while maintaining the ability to travel. As Archigram conceived it, the machines would choose movement patterns based on resources.  

Figure 7: Archigram's A Walking City. Ron Herron, 1964.
CONTEMPORARY APPROACH

While Archigram’s concepts for the Walking City may seem improbable if not impossible at full scale, the idea has been attempted and prototyped. The contemporary approach was taken on by the art collective N55, founded in 1994 and based in Copenhagen, Denmark. The art collective displays their pieces all over Europe and base their work on architectural forms and systems. Similar to Archigram, N55 focuses on what architecture can be, and not what it already is or has been. One example that shows direct comparison between the two design groups is N55’s newest work entitled “Walking House”. The project, initiated by Wysing Art Centre in Cambridgeshire, England asked N55 to collaborate with a group of travelers from around Cambridge to rethink dwellings. Cambridge itself has traditionally been “home” to a large population of travelers who have lived in a symbiotic relationship with the locals, such as for seasonal farming. However, current farming and economic practices have decreased the needs for seasonal workers, causing harsh conditions for established travelers. N55 decided to see if it was possible to rethink a nomadic approach to dwellings, and even suggest new meanings of a nomadic culture and symbiotic relationship with their surroundings.23

Figure 8: N55's "Walking House" prototype (2008).
While N55 has not noted inspiration for their work from Archigram’s Walking City, their Walking House concept applies a similar approach to moving dwellings. N55’s Walking House is not like the typical mobile home, but modular dwelling that enables the user to live in peace with their surroundings, moving slowly through a landscape or city by literally walking. N55 recognized that in order for the Walking House to be practical, it should have minimal impact on surroundings and not be dependent on existing infrastructure for support. The home is equipped with solar cells and small turbines for power production, rain water collector and solar heater for water needs, composting toilet, attachable green space for food, and a small wood burning stove for heating and cooking. N55 designed the system in a hexagonal form that allows for interconnection with other Walking Houses. This concept is highly reminiscent of Archigram’s work. This interconnection concept is what made such work as the “Walking City” concept plausible, not individual dwellings in the same space, but an interconnected system that can be formed when desired and broken apart just as quickly.  

![Image](image_url)

**Figure 9:** “Walking House” connection concept.

Archigram was one of the first well-known groups to reevaluate the concept of architectural site. While typically a site becomes static, Archigram explored the possibility
for users to relocate their dwellings, and thus move site, in different ways throughout their work. The “Plug-In City” is about establishing a system that supports the needs of users and dwellings, but not a design for dwellings themselves. In this way, the “Plug-In City” would allow users to bring their ideal dwelling to the site and simply connect it to the system supports. However, because a “plug-in” dwelling cannot move itself, users are still dependent on specialized moving companies, an issue that is potentially diverted by the “Walking City”. In Archigram’s concept of a “Walking City”, the dwellings simply move themselves in accordance with user needs. While once seen as an “impossible” concept, N55’s “Walking House” prototype shows that the Archigram concept was not entirely outlandish. These moving dwelling concepts allow for users to simply bring their dwellings with them, allowing for a site control measure of “user autonomy”. Desirable sites are about proximity to sought-after locations, and while the dwellings here in concept can move, it cannot guarantee desired sites. The Archigram concepts may be infeasible as designed, but they promote an ideal that can be understood as establishing a high level of user control over architecture.

(2.2.3) SUPERSTUDIO

The avant-garde works of Italian founders Adolfo Natalini and Cristiano Toraldo di Francia was a reaction to the Italian economy in the 1960’s. In 1966, Natalini and Francia looked to start practicing architecture in Florence, Italy. But as the city was still recovering from WWII, leaving little chance for newcomers to build, or even teach architecture. However, around the same time international avant-garde magazines featuring the works of architects in the U.K. group Archigram, pointed the way for architecture to be developed as criticism of the built environment instead of becoming part of it. Due to varying degrees of professional protest and modern influencers, Natalini and Francia became involved in a different kind of thinking, forming Superstudio to practice architecture not as traditional architects, but more as architectural artists. Superstudio was another architecture that played a major part of the “Radical” architecture movement.
Superstudio’s first reaction was to strip away the modern meaning of architecture. One result was the notable development of “The Grid”, an architectural equalizer that became a basic element in their early works. To Superstudio, the grid would become the standard form for all future architecture, a “single continuous environment, the world rendered uniform by technology, culture, and all the other inevitable forms of imperialism.” In concept, the grid represented a truly democratic human experience that every point of the grid was identical, with no architectural space being better than another. The magazine image series of photomontages showing iconic places like Midtown Manhattan, or the Taj Mahal wrapped in the grid, in and of themselves became iconic symbols, capturing the imagination of young architects everywhere (Figure 10). But more influential than any individual project, and perhaps even Superstudio’s core criticism of architecture and modernism, was the idea that an architectural practice could be conceptual and theoretical, concerned with cultural criticism rather than the production of buildings. Natalini, in 1971 wrote:
“...if design is merely an inducement to consume, then we must reject design; if architecture is merely the codifying of bourgeois model of ownership and society, then we must reject architecture; if architecture and town planning is merely the formalization of present unjust social divisions, then we must reject town planning and its cities...until all design activities are aimed towards meeting primary needs. Until then, design must disappear. We can live without architecture...”

Superstudio’s distaste for modern architectural systems became the underlying foundation for such work as their iconic “Grid” that as noted prior was about creating an architectural uniformity. While uniformity may have been an architectural equalizer, bringing all users to the same level, the “Grid” was a critique, and as such without detail on usage or application. But, upon further reflection, it became apparent that one approach for establishing a level of “user autonomy” within or as an architectural concept could come from a uniform system. If for instance spaces were uniform and devoid of unique distinction prior to the users ability to govern or control them, then they would not be a factor when searching for the “right space”.

(2.2.4) HAUS RUCKER CO.

Haus Rucker Co. (direct translation: House Mover Company) was a Viennese group founded in 1967 by Laurids Ortner, Günther Zamp Kelp, and Klaus Pinter, later joined by Manfred Ortner. Like the other groups mentioned prior, Haus Rucker Co. became one of the influential groups of the “Radical” architecture movement of the 1960’s. However while groups such as Archigram, and Superstudio conceptualized and printed in magazines, Haus Rucker Co. explored the performative potential of architecture through installations and happenings. While on one hand, Haus Rucker Co.’s approaches to architecture were a cultural critique, the other hand was the possibility of creating designs for technically mediated experimental environments and even utopian cities.

To influence and inform the general population, Haus Rucker Co. created installations and happenings where the viewers became participants that could influence their
own environments and not be passive onlookers. The installations were typically inflated structures such as *Oase No. 7* (1972), created for Documenta 5 in Kassel, Germany. *Oase* No. 7 was an inflatable dome structure attached to the façade of Museum für Kunst und Gewerbe several stories in the air (Figure 11). This “outdoor” space created in the dome was intended to instill a sense relaxation and wonder in its users.²⁹

![Figure 11: Haus Rucker Co.’s Oase No.7.](image)

Haus Rucker Co.’s work served as a critique to the confined spaces of typical architecture by designing temporary and disposable architecture. Although impermanent, such a structure addresses site and form autonomous function potentials of architecture, and stand as a reminder that solidity is not necessarily essential in architecture.
CONTEMPORARY APPROACH

Haus Rucker Co.’s blurred the lines of defined structure with their “disposable” architecture, and surly would appreciate the creations by the present company Bubble Tree. In a similar fashion to Haus Rucker Co.’s “Oase No. 7”, Bubble Tree has designed and created a line of inflatable architecture. While some may see Bubble Tree’s products as a new tent concept, the product is closer to an inflatable home. Each product is designed to increase the users proximity to nature, create a minimal environmental impact, and provide an economic solution of “luxury” while camping.

Just like “Oase No. 7”, the Bubble Tree tent is an inflatable spherical dwelling with a 360-degree line of sight (Figure 12). While some designs incorporate partial opaqueness, the whole idea is that users can view nature even while inside their tents. While privacy may seem like an issue, the tent is intended for those adventurous enough to go beyond the beaten path and beyond other human sight, making privacy of little importance. However if privacy is wanted, designs are available in half-opaque, varying on the users desired degree of environmental exhibitionism. While Bubble Tree’s tents provide shelter, they are far from being just that. The basic design comes complete with portable wardrobes, sofas, rollout beds, and even optional electricity for lighting. As a secondary option, attachable bathrooms and secondary bedrooms are options, and with such features, the realm of camping becomes less about “roughing it” and more about enjoying nature.
Beyond the idea of a tent, Bubble Tree also has a line of inflatable tree houses, another similarity to Haus Rucker Co.’s usage of existing structure to support their temporary architecture. While Bubble Tree does not directly credit Haus Rucker Co. for their inspiration, the similarity in concept is sufficient to show the implications and application of similar architectural approaches. User autonomy (as pertinent to this work) is about the users ability to control their architectural spaces, and in this instance about obtaining the ability to quickly create and move their dwellings.

Haus Rucker Co. conceptualized that architecture does not have to be either rigid or “solid”, but that it can be impermanent, inflatable, and even disposable. While less of a critique on architecture, but more as a reaction to it, Haus Rucker Co. gave users the ability to experience architecture in new ways by creating both works of extension, from the example of Oase No. 7 and individual inflatable dwellings. But beyond inspiring a new form of architecture, works like Oase No. 7 also establish new levels of user autonomy through mobility (by the actual user and not architecture), and quick modification or changeability. This is perfectly demonstrated by the modern company Bubble Tree’s inflatable dwellings like the “Cristal Bubble” tent. Unlike traditional tents that simply provide shelter, users have all the amenities expected of a home, and as Haus Rucker Co. established, it is impermanent and mobile. By considering the concept of impermanence and its application to architectural design, yet another aspect of user autonomy can be developed into a functioning architectural design.
CHAPTER 3: EXISTING SPATIAL AND UTILITY REQUIREMENTS

In order to move forward, we often have to look back. Buildings, whether residential, commercial, or industrial, have evolved from early human shelters. Like all animals, humans sought to protect themselves against a world that is not always attuned to our physiological needs. When it is hot, shelter can provide shade, when it is cold, shelter can contain warmth, and when it rains shelter can keep us dry. Today’s buildings however are much more complex than early human shelters. Each improvement upon these early shelters for comfort or convenience was first a novelty, but soon became standard practice, until finally it became an expected minimum. Because of this, buildings today are far from being strictly shelters, but now are equipped with utilities such as water and electricity. Our buildings have become comprehensive life-support mechanisms for its users. As such, building design should reflect the current and potential needs of the user, so it becomes important to understand current spatial and utility elements of a space. Examining major spatial and utility components of the interior space, we can understand what they provide for the user, and reevaluate their usage in order to better serve the user’s needs.

(3.1) SPATIAL BARRIERS

**bar·ri·er** [bar-ee-er]  
noun  
1. anything built or serving to bar passage, as a railing, fence, or the like: People may pass through the barrier only when their train is announced.  
2. any natural bar or obstacle: a mountain barrier.  
3. anything that restrains or obstructs progress, access, etc.: a trade barrier.

Physical and visual barriers can define or be part of the space that users occupy. These elements manifest themselves within architecture as walls, ceilings, and floors. They can simply be understood as spatial barriers meeting functional needs. By understanding an architectural space in this way, what is typically treated separately as a wall, floor, or ceiling, can be treated the same, leading to interchangeability or even removal from the space without
functional loss. This section will discuss the user needs for **protection** and **privacy** by spatial barriers that form their space, and what physical and visual needs are required to achieve those needs.

(3.1.1) PROTECTION

Protection is the most fundamental need required from any architectural space. As discussed in the introduction, early humans created shelters in order to protect themselves from climate, animals, and unwelcome visitors. This early need for shelter is still relevant, as climate can still provide uncomfortable and potentially dangerous conditions such as wind, rain, or extreme temperatures to name just a few. Protection or separation is still important, even more so with the addition of security. While early humans may have only needed these protective measures applied to the outer portions, current users may need protective measures for inner spaces when “natural” elements such as water and climate are brought into these spaces, or to potentially limit interior spaces from unwanted occupants. This section will consider protective barriers independently as **climate barriers** (thermal and vapor) and **movement barriers**, considering both their exterior and interior applications.

(3.1.1-1) CLIMATE BARRIERS

Climate barriers are barriers that help prevent and control the movement of heat and/or moisture through a space. Both are needed for comfort and protection of the occupants as well as for building protection. As such, some materials or assemblies create better thermal climate barriers, while other materials or assemblies are better moisture barriers. Some of the most effective climate barriers are not physical, such as vacuumed compartments. The level of thermal and moisture barrier protection needed is simply dependent on the following factors.
THERMAL BARRIERS

One of the major factors to maintaining temperature and thermal comfort in a space is through adequate application of both exterior and interior insulation. Insulation is any material that slows the heat transfer between two spaces and the traditional material type needed within a thermal climate barrier. Typical insulation materials for buildings are rigid foam insulation, batted or soft insulation, and blown insulation. Each insulation serves to fill the void and space between the exterior and interior wall space. For exterior wall application, local building codes are determined by state and building type. The state of Iowa, for example, has adopted the 2009 International Energy Conservation Code (IECC) for residential insulation standards, and the 2009 IECC with reference to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1-2007 for commercial insulation standards. The 2009 IECC divides the United States into zones. Each zone has separate base insulation standards to maintain a moderate level of energy conservation by preventing heat loss. These standards are mandatory for any building with an adaptive spatial system, promoting thermal comfort, and important for user consideration.

Interior insulation, however, is not clearly defined within building code, as it is typically only placed to maintain non-thermal user comfort. While some instances may require thermal breaks between spaces, typically interior insulation acts as an audio barrier. If a thermal break is needed, exterior insulation code applies. However, if an audio break is desired to maintain user privacy, sound insulation guidelines and assemblage should be followed. Audio barriers will be covered later in this chapter.

VAPOR/HUMIDITY BARRIERS

The second major element of thermal comfort is humidity. While typical air conditioning units remove excess humidity from the air pumped into a space, there are several considerations that still must be noted. First, according to 2009 IBC, buildings are required to provide vapor barriers to prevent excess moisture from transferring from the exterior to the interior. Moisture transfer prevention is important to protect the wall
assembly from naturally occurring condensation, which can lead to potential damage by rot, mildew, and fungus growth. Another method of climate/humidity control is adequate ventilation. While the ventilation units primarily circulate and provide fresh air, when paired with air conditioning units, it can remove excess moisture while cooling the space. Proper moisture ventilation control is crucial in spaces such as residential bathrooms where high humidity levels are associated with baths and showers. International Mechanical Code (IMC) 403.2 stipulates that if residential bathrooms do not have an operable window, they must be equipped with a mechanical ventilation system. This ventilation system must discharge air to the exterior of the building as high moisture content air would not be wanted for recirculation. Since high humidity levels are associated with bathrooms, any interior bathroom wall should have either a vapor barrier or be mold resistant.

If a space would contain an adaptable bathroom area, vapor control becomes an issue, as all surrounding barriers would need to form an adequate seal and be mildew resistant. Secondly, the ventilation system requirement means the addition of not only a fan, but also ducting to direct the air it to the building exterior. This ducting requirement complicates adaptability, but also provides a potential chance that users would ignore its use or placement and risk building damage.

(3.1.1-2) MOVEMENT CONTROL BARRIER

Physical movement barriers enforce not only control within a space, but also security and support. Preventing physical movement, these large physical barriers are typically the easiest to identify. Typical walls, ceilings, and floors are perfect examples of physical movement barriers, as they define the spatial parameters (control), prevent unwanted user access (security), and provide walking or hanging surfaces (support). Movement control barriers can range from a “full” physical movement barrier that offers support, control and security, to implied movement barrier that allows for spatial control without physically preventing movement.
A “full” physical movement barrier is any barrier that prevents all movement or passage by users and or objects. Any solid material can act as a full physical movement barrier with the security and support properties dependent on the material strength. For example, gypsum clad walls and ceilings provide movement control and adequate security for most residential and business usage but provide little structural support. While materials like gypsum independently can work as full physical movement barriers, it cannot provide the needed support for uses such as flooring. Heavy cloth such as curtains too can act as a full physical movement barrier, covering an entire space. Curtains however obviously provide less control security and support.

Partial physical movement barriers are any physical barriers that partially cover a space or are perforated. Half walls, like 3 ft. walls within a 7 ft. tall space, do prevent movement between spaces but provide for no security. Perforated surfaces that divide spaces, such as metal with perforated holes also act to control movement, while providing a level of security. As example of a perforated partial physical movement barrier, buildings such as banks and prisons utilize bars to control the movement through spaces such as vaults or cells. While the bars limit movement control, they allow for visual connection and allow for some security protection understanding that body extremities could still pass through.

Implied physical movement barriers are any environmental change or suggestion of spatial separation that cannot actually prevent user movement, provide security, and offer little support. Examples of implied physical movement barriers are spaces that contain depth changes of floor, ceiling, or walls. Whether the surfaces are raised, lowered, pushed in, or pulled out, they imply spatial segregation and to detain users within defined spaces. While these spaces may have the least amount of control physically, the level changes imply separation, keeping users within spaces that have full or partial physical movement barriers. It should also be noted that lighting devices, which has no physical presence, also define the parameters of a space, and just as effectively establish a level of movement control.
Figure 13: Movement barrier material example chart.

(3.1.2) PRIVACY

The word privacy, from the Latin word *privatus*, means "separated from the rest, deprived of something", from *privo* "to deprive". Privacy is the user ability to seclude or prevent the spread of sensory information to other occupants. The difficulties with designing for privacy are boundaries and content differ among users. As privacy levels vary and user dependent, it must be broken down into common spatial themes and understood individually. Social psychologist Stephen Margulis breaks privacy down into a process of information management. Margulis states privacy is a simple means of withholding personal information gathered by human senses. Having six senses (vision, touch, taste, smell, hearing, and kinesthesia), this section will discuss the extent of privacy that can be created by blocking visual, audio, and/or olfactory information using barriers. Of the six senses, three senses provide user or spatial information even with distance, and therefore the barriers users would utilize in protecting their “private” information.
VISUAL BARRIERS

Visual barriers enforce visual privacy, lighting control, and psychological wellbeing. Noted sociologist Erving Goffman has argued users need the ability and space for “off stage” activities. These off stage spaces allow users to relax and prepare for later “public performances”, which they may or may not want observed. Once in place, they prevent visual information about one user reaching others in the same interior space or exterior space by blocking or skewing visual pathways. The barrier simply must block visual information pertaining to the user and not necessarily light. When light control or prevention is needed, such as controlling or preventing natural light, visual barriers also provide this benefit.

If complete visual privacy and light control is needed such as for bedrooms, then blocking not only visual pathways but also outside lighting becomes important. In such cases, completely opaque materials are used. Opaque materials can range depending on other user demands for the barrier. For example, typical gypsum clad surfaces offer complete visual privacy while also acting as a partial auditory, olfactory, and movement barrier. However, if visual control is the only demand placed on the barrier, than typical gypsum class surface may be overdesigned and provide inflexible for other spatial usage. Heavy fabrics may be employed for full visual privacy while allowing for other elements such as audio, olfactory, and movement to pass through the fabric. If full visual privacy is not needed, then the user can decrease opacity to allow some light into the space or some visual information out. Frosted glass or sheer fabrics are examples of partially opaque materials that skew the visual information and allowing for other information to pass through. Such a need for partial visual barriers can be used in office spaces or shower facilities, which allow other users to know if a space is occupied without compromising privacy by allowing some light to pass through. Obviously at the other end of the spectrum, clear glass provides little to no visual privacy. The only exception to this is when glass reflects back bright lighting known as the “scrim” effect. A user can be inside a building during a bright day and see outside the building, but disallowing people outside to see into the building.
AUDIO BARRIER

Audio barriers are barriers that prevent or reduce sound from moving through it, and therefore enforce audio privacy and protection. In this way, environmental psychologists Miller and Schlitt closely relate audio barriers to visual barriers. Users have conditions where they would not like to be heard or want to control what they are hearing.\textsuperscript{35} As the audio barrier effectiveness is dependent on their material’s ability to obstruct sound waves from transferring, the barrier can fall under one of two types, reflective or absorptive. The type of audio barrier is dependent on users need for the space. Also similar to visual barriers, audio barriers can limit sound being transferred within the same interior space or to the exterior space. Using one or both types of audio barriers can vary the degree of audio privacy and protection needs for any user.

Reflective audio barriers are those materials and surfaces that when placed in a space act to change and enhance the directions of sound waves. Sound waves are longitudinal energy waves of compression and rarefaction that cause vibration through any elastic material, such as the air or water. As sound waves are dependent on elastic media for transmission, any dense material will reflect sound, changing the sound waves path depending on the striking angle. Typically, the smoother and dense the surface, the more sound waves are reflected without energy loss. If these types of surfaces are to be considered for promoting audio privacy, they should be used when privacy is desired between to closed-
off spaces. Reflective audio barriers can also promote sound transmission and control within the space. The act of carrying sounds through by reflection is prevalent in auditoriums, as the walls and ceilings are designed to reflect sound effectively toward each user and occupant of the space.

Absorptive audio barriers are those materials and surfaces that when placed act to absorb or contain sound waves. Absorptive materials in fact act in the same fashion as reflective materials. A good audio reflection is based on smooth and dense materials, while a good audio absorption material is based on porous and low-density material. As sound waves strike an absorptive surface, they enter the porous surface and reflect constantly, losing energy with each reflection. The low-density material allows for more vibration within the material promoting energy loss. Absorptive materials provide a place for sound waves to lose all energy and discontinue transfer. While not typically thought of a barrier, the use of absorptive materials throughout a space can effectively deaden sounds, and do not break or compartmentalize a space like visual barriers. In this way audio barriers can act independently from other barriers, allowing audio blockage without obstructing other elements such as vision or movement. Examples of absorptive audio barriers include thick wall-to-wall carpeting, heavy fabric curtains, acoustic ceiling tiles, etc. However, when a space has a high load of audio absorption materials, the space will be quieter than a space with reflective materials as sounds will not reflect across the space. This level of internal spatial privacy would work well in spaces such as libraries, but would be inappropriate for social or musical applications.

![Audio barrier example scale from absorptive to reflective.](image)
Architectural designers must be familiar with the assemblage of audio barriers, as within architectural constraints, sound transmission between spaces such as leasable spaces should be minimized. One way to understand sound transmission is by Sound Transmission Class (STC). A STC rating is an integer rating of how well a building partition or barrier attenuates airborne sound and material vibrations. In the US, this standard is widely used to rate interior partitions, ceilings, floors, doors, windows, and exterior wall configurations based upon the American Society for Testing and Materials International Classification (ASTM) (E413 and E90) for the sound transmission of specific materials. Outside the USA, the Sound Reduction Index (SRI) standard is used.

Table 2: STC levels and occupant hearing capacity.

<table>
<thead>
<tr>
<th>STC</th>
<th>What can be heard</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Normal speech can be understood quite easily and distinctly through wall</td>
</tr>
<tr>
<td>30</td>
<td>Loud speech can be understood fairly well, normal speech heard but not understood</td>
</tr>
<tr>
<td>35</td>
<td>Loud speech audible but not intelligible</td>
</tr>
<tr>
<td>40</td>
<td>Onset of &quot;privacy&quot;</td>
</tr>
<tr>
<td>42</td>
<td>Loud speech audible as a murmur</td>
</tr>
<tr>
<td>45</td>
<td>Loud speech not audible; 90% of statistical population not annoyed</td>
</tr>
<tr>
<td>50</td>
<td>Very loud sounds such as musical instruments or a stereo can be faintly heard.</td>
</tr>
<tr>
<td>60+</td>
<td>Superior soundproofing; most sounds inaudible</td>
</tr>
</tbody>
</table>

OLFACTORY BARRIERS

The ability for humans to smell is directly connected to the intake of air in which “smell” travels. To prevent unwanted smells from one space to another, a barrier must be put in place to prevent air movement. While not all air movement barriers are intended to prevent smell transfer, they do inadvertently act to do so. The exception would be for a
filtration system and venting to “catch” the volatile compounds. The purpose for smell barriers includes privacy, courtesy, and protection.

Like visual and audio barriers, some users want to contain the smells that are produced within a space out of courtesy for other users. Events that require separating individual interior spaces, such as rest rooms from surrounding spaces, smell barriers becomes the separating element. Because air has the ability to flow through any porous or open surface, materials such as fabric do little to prevent air movement. Instead, smell or air movement barriers need to be a solid, non-porous surface. For this reason, most traditional full walls, floors, and ceilings act as smell and air movement barriers. Typical gypsum clad construction, glass or plastics do well to prevent air movement. It is possible to allow visual connections while preventing volatile compounds or air connection within a space. When air does penetrate through the barrier, like through a doorway, seal, or overlapping materials may be used. It is typical to find restrooms incorporated with a venting fan, which draws air out of the space to create negative pressure in the room and minimizing air transfer to adjacent areas. The same methods can be applied for separating interior from exterior spaces. In these instances where odor may be an issue, it may more important to provide barriers or increased ventilation to protect user privacy and courtesy. In locations such as apartments, the mixing of smells in hallways may prove to become overwhelming or nauseating to other occupants of the building.

Regulations can dictate the storage of chemicals, as some chemicals can produce volatile odors that may be toxic or dangerous for human inhalation. For this reason, rooms like wood shops, utility closets, or paint spray rooms that store chemicals, paints, or stains, must be built with olfactory barriers. In such areas, the space must be fully encapsulated (having all solid separating surfaces). The IMC article 502.7.3.3 require a minimum average air velocity of 100 ft/min across the direction of airflow. To meet this requirement, ventilation fans are installed, creating a second olfactory barrier within the space.
(3.2) SPATIAL UTILITIES

utility [yoo-ti-tee]
noun, plural -ties
1. the state or quality of being useful; usefulness: This chemical has no utility as an agricultural fertilizer.
2. something useful; a useful thing.
3. a public service, as a telephone or electric-light system, a streetcar or railroad line, or the like. Compare public utility

Utilities form the non-spatial functions of an architectural space that are typically regulated by building codes. These utilities help to provide climate comfort, service support, and convenience for the users.

(3.2.1) CLIMATE COMFORT

The term thermal comfort as defined by American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) is the state of mind that users express as satisfaction with the surrounding environment. As the term would suggest, thermal comfort differs from user to user within an adaptive building space or any well designed space should allow users to control the Heating, Ventilation, and Air Conditioning (HVAC) system to achieve comfort. Users experience thermal comfort through the transfer of body heat by conduction, convection, radiation, and evaporative heat loss. But it has been recognized that the sensation of feeling hot or cold is not just dependent on the air temperature alone, and also includes:

- Personal factors (health, psychology, sociology, and situational factors)
- Insulated clothing (Clo Value)
- Activity levels (Met Rate)
- Air movement (Wind Chill Factor)
- Surface temperatures
- Relative humidity

But even while each user may have differing degrees of thermal comfort, generally comfort can be achieved by abiding to the psychrometric chart developed by Willis Carrier in 1904\(^3\) (Figure 16), which takes into account temperature and humidity levels to predict average user thermal comfort. However as stated prior, when applied within an adaptive space, users should be able to easily control the HVAC system in order to achieve thermal comfort levels.

![Figure 16: Psychrometric chart with comfort zones.](image)

**HVAC**

HVAC systems are the most important element in regulating users comfort levels as they refer to any technology or equipment that helps regulate indoor environmental comfort. Beyond comfort, HVAC systems are important for safety and healthy buildings standards by regulating temperature, humidity, and fresh air for indoor usage. While the three central functions of HVAC systems are understood independently from each other, modern building
practices integrate the design, installation, and control systems of these functions into one or more systems. For smaller buildings, contractors can determine the sizes HVAC systems and equipment needs using simple calculations based on building codes. For larger buildings however, building services designers and mechanical or architectural engineers, will analyze, design, and specify the HVAC systems and specially commission them for the intended building. Whether small or large, building permits and code-compliance equipment inspections is typical and helps to promote quality for the users.

Within both residential and commercial buildings, the typical HVAC design method is a centralized system. The principle behind centralized HVAC units is to produce the desired heating, venting, or cooling at a single location within a building and then distribute it throughout. As example, central heating units encompasses the use of such systems as boilers, furnaces, heat pumps to heat water, steam, or air in the central location such as a furnace or mechanical room. The most typical method in the U.S. of distribution of heating, venting, and cooling energy is by a forced air system that uses air as a transfer medium. These systems rely on ductwork, vents, and plenums as means of air distribution, separate from the heating and air conditioning systems. The return air supply carries the air from several large return vents to a central air handler for re-heating or conditioning while the supply duct/plenum directs air from the central unit to the rooms which the system is designed to heat, cool, or vent. When water is used as a heating or cooling medium, known as hydronics, piping is used to distribute the heated fluid to radiators to transfer this heat to the air. The term radiator is misleading as most heat transfer from newer systems is actually by convection. An example of this system is in-floor hydronic coils that pump water into coils, transfer heat through the floor (typically stone, tile, or concrete) and move the water back to the water heater for reheating.

Another method of employing HVAC within a space, either typical or adaptable, is using solar heat. The principal behind this technique is to turn the incoming solar radiation into a manageable heat source. This technique requires at minimum of 0.18-0.38 ft² of south facing glass for every square foot of open heated space, and a thermal mass equivalent to 150 lbs. of masonry for every square foot of that glass (or the equivalent of 4 gallons of water).
By utilizing outdoor overhangs or light shelves, the amount of light that enters the space can be regulated seasonally. During the winter when the sun is needed for heat, light can pass under outdoor overhangs and enter the space. During the summer when the sun is higher and heat is unwanted, the same outdoor overhangs prevent the heat from entering the space. This system as is, is considered a passive solar system. While passive solar systems can be effective, it can difficult to regulate and typically more user friendly to utilize mechanical systems. Forced air of the HVAC system assist with passive heating, by moving the warm air through the house mechanically. This mechanical assisted system is considered a hybrid solar system, and has fewer limitations than the passive system alone.

When considering HVAC systems within an adaptable situation, a few things must be designed differently than in traditional situations. While it may be possible to utilize a type of flexible ducting that can easily move and compress for users to place vents where needed for forced air. A potential inconvenience for users is to manage ducting. Therefore, an adaptable HVAC system within an adaptable space should attempt to minimize the size and interaction required with users. While most residential buildings utilize ducting, commercial buildings have begun to utilize under floor air distribution systems in conjunction with raised floor systems for cable management. The adaptability benefit for this type of HVAC air distribution system does not rely on ducting, but instead open networks of spaces or plenums. If a solar heating system available for an adaptable space, the issue of thermal mass placement must be addressed by the designer and not interfere with the users ability to adapt the space as needed. Any adaptive solar heating system must have the required thermal mass either outside of the users space, such as under the floor, or part of the designated outer constraint, such as an exterior wall. Lastly, the designer determines whether to utilize a centralized HVAC system against the alternative of localized HVAC systems. While a localized system such as space heaters would maximize spatial adaptability, buildings in cold climates need to maintain above 50 degrees Fahrenheit for both building and user protection. While the size and special connections are needed for central HVAC systems, it is not feasible for users to move the system. If a central system is utilized for an adaptable space, the unit should be placed where it will be out of the way of the adaptable space to maximize room usage.
(3.2.2) SERVICE SUPPORT

ELECTRICITY

From powering modern devices such as computers and lights, to providing energy for other utilities such as HVAC systems, modern living would not be possible without the use of electricity. Like HVAC systems, electricity is considered a crucial service to building users, and is both mandatory and regulated by building codes such as the National Electrical Code (NEC). NEC Article 210.52 specifically defines electrical outlet spacing, a key point in architectural design. The current 2011 NEC requires electrical outlets on any wall over 2 ft. in length, within 6 ft. of any door or room entrance, and no more than 12 ft. apart. While this 6/12 rule has become a rule of thumb for most designers, care must be taken to facilitate for the users usage of electrical equipment and devices.

While the NEC is necessary for insuring both building standards and safety, some issues arise when the code is used as a design guideline. First, while the 6/12 rule provides the adequate average amounts of electrical outlets, it does not take into consideration where those outlets are needed. Evenly spaced outlets along a wall may provide a standardized convenience, but often are typically not sufficient. In offices and residential settings, electrical devices such as computers are often placed alongside their electrical accessories such as external hard drives, printers, charging stations, etc… thus the need for more outlets in one location. In buildings where the users are leasing, often power strips and extension cords are required to meet users electrical needs despite fire code regulations. This not only places unanticipated power loads on circuits, but the use of extension cords can become both fire and tripping hazards if not properly used and maintained by users. This same issue becomes even more of a hazard if electrical equipment and devices are not lined against a wall where outlets are placed.

Another potential issue with minimum electrical code designed buildings is the ever-growing usage of electricity and electrical devices. According to public data, the average person in the United States in 2008 used 13,654 kWh per year. This is the equivalent to leaving a 100-watt light bulb for 5,690 days continuously. As seen in Figure 17, the amount
has increased steadily over the years, and likely to increase as electrical devices become more integrated into our businesses and personal lives. The standards for electrical usage within architecture today will be insufficient in the next decade if not sooner. As mentioned in the prior chapter, a leading cause for both renovation and demolition of buildings is utility insufficiencies, most commonly electrical. While renovations can rectify the issue in most cases, current building practice place electrical outlets within walls. Because of this practice, renovation costs not only include the additional electrical equipment and wiring, but also wall renovations including demolition and surface material replacement. Adaptability in architecture should aim beyond users to change the spatial elements of their spaces, but also allow ease of adding and moving electrical utilities and without major construction or safety issues.

**United States Electricity Consumption Per Capita**

![United States Electricity Consumption Per Capita](image)

Figure 17: U.S. electricity consumption per capita.\textsuperscript{38}

PLUMBING

While technically plumbing is considered a series of pipes, fittings, and tanks that move either liquid or gas from one location to another, within the constraints of this thesis, plumbing shall refer to the system pertaining to the movement of water. Water is a crucial
requirement for modern buildings as it has vital roles in drinking, cooling, and sanitation. Within both commercial and residential applications, plumbing can be broken down into two systems that work independently from each other, water supply and waste return. But beyond receiving water and removing waste, other systems such as water heaters are needed to provide water at controllable temperatures.

All water used in buildings comes from either a ground-water source, such as a well, or from a surface-water source, such as a river, lake, or reservoir. In the U.S. it has been estimated that 85% of the residential population receives water by public departments. Water departments station water tanks that exist for storage, sanitation, and pressurizing the plumbing network by gravity or pumps. Within a building, water receiving receptacles such as faucets, can open a valve and start the water flow. In the U.S. a non-conserving water single family home uses 80-100 gallons of water per capita per day. While some water is expended from drinking, most water will exit the building after usage by return piping. Every building produces two types of water return, grey water and black water. Grey water is the wastewater that is produced through activities such as laundry, dish washing, bathing, and most sink water. What makes grey water different from black water is that the contaminants added to white (clean) water are minor such as soaps and food particles, which are not harmful for human contact. Black water is any wastewater produced with human waste, such as toilet water, or harmful chemicals from commercial applications. Black water can be hazardous, and therefore must be disposed of effectively and properly. The important wastewater clarification for this thesis is users cannot be allowed to adapt any item involving black water disposal for health safety reasons. Items such as toilets would be required to have a fixed position within an adaptable space, while items placed alongside toilets such as sinks could be adapted.

Separate from supply and return, appliances such as water heaters interconnect with plumbing to provide another crucial building element. Typical water heaters are developed as tanked or tank-less. Tanked water heaters store a percentage of incoming water, heating it in a central location to provide hot water for users. They can be large in size and heavy, such units could not be moved easily in an adaptable situation. However, smaller units that are not
central and are instead localized may provide an alternative movable solution. Tank-less water heaters, also referred to as in-line water heaters, are units that heat water as it passes through the unit for usage. Smaller in size than any tanked heater, tank-less water heaters also do not use as much energy as the tanked counterparts. Water is heated on demand and not constantly maintained at a specific temperature. This unit could be moved or adapted within a space by the user, due to a manageable weight.

(3.2.3) CONVENIENCE

Along with electricity, other outlets are placed within residential and commercial buildings to add convenience and provide access to communication technology for the occupant. The most notable are LAN line phone, cable, and Ethernet outlets. Building practices have standardized the size and shape of these outlets to align with the typical electrical outlets. While electrical outlet placement is subject to the NEC Article 210.52, these other convenience outlets placements are left to the discretion of designers. The issue is that each space typically needs only one of each outlet, and thus the placement of the outlet also dictates the placement of the equipment that utilizes it, reducing spatial arrangements by the user. If the user decides on alternate placing, long cables or wireless equipment is required, creating an unsightly and potential tripping hazard. Within an adaptable space, users should determine these outlet placements a similar fashion as the electrical outlets. Such choices maximizes user’s options prevents potential hazards and boosts spatial aesthetics.
CHAPTER 4: ADAPTABLE DESIGN SYSTEMS

Chapter 1 rationalized that architectural issues of C&D waste and user spatial control could be diminished through user controlled adaptability application in architectural schemes. Chapter 2 demonstrated that other countries and designers have recognized these issues and have proposed solutions of adaptability or flexibility to solve them, along with other methods of user control. Chapter 3 became the stage for understanding the required needs of a space for users, along with potential issues and methods of approach for adaptability. This chapter proposes an adaptable system and illustrates a potential solution toward these architectural issues. This chapter will demonstrate a forward step from previous works and provide for spatial needs and the user.

In order to understand the proposed user controlled adaptable space system, this chapter is broken down into three sections; adaptable systems support structures, adaptable barrier systems, and adaptable utility systems.

(4.1) ADAPTABLE SYSTEMS SUPPORT STRUCTURES

In conjunction with adaptable systems design for spatial elements and utilities, structural systems must also be considered to meet the structural requirements, user demands, and building code. The supporting structures have been designed with typical U.S. construction methods in mind to minimize the need for specialized producers, equipment, and installation training for construction crews. Beside construction waste reduction, retrofitting an existing building with these adaptable systems would reduce renovation waste and minimize expenditures.

While the entire adaptive system supporting structure can be a single assembly, this section focuses on individual parts of that assembly in accordance with what will be directly supported. These individual supports will be the floor support, and the ceiling/wall support.
(4.1.1) FLOOR SUPPORT

In order to support the adaptable panel cladding system, which will be covered in the next section of this chapter, a raised flooring system provides design basis for the structural support of the flooring. A typical raised floor system is composed of a series of supported panels that provide a floor level elevated above the floor plate. Typically these systems are used in commercial application to contain abundant wiring, and enable quick alterations and easy additions. Raised floor systems have other benefits such as the potential for efficient under floor air distribution systems for heating, cooling and venting. Typical raised floors systems are placed over existing floor plates adding additional cost to flooring installation and construction due to an overall building material and spatial height increase. Instead typical construction methods were considered and adapted to provide the benefits of a raised floor system without additional cost by utilizing the existing cavity spaces between common floor/ceiling joists.

Of the common floor/ceiling joist options typical of residential and commercial construction, trusses are chosen for several reasons. First and foremost, trusses are available in required spans and load support without being excessively deep. Second, in opposition to a solid joist such as typical wooden or steel joists, trusses utilize reduce production material. Lastly, as opposed to wooden or steel I-beams, truss construction includes multiple openings that can act as utility pass through points. As such, a truss provides a financial, environmental, and efficient choice for the structural element for adaptive systems. In construction, the trusses should be placed at 24 in. on center. The rational for the wide spacing is to create a standardized floor and ceiling grid for adaptive panel cladding and spatial separators such as counters or adaptive walls. This spacing is also considered efficient as it minimizes material waste of standard sized materials such as underlayment, which is manufactured at 48 in. x 96 in. While other efficient truss spacing options such as 16 in. or 19.2 in. would also minimize waste, they would compromise the spacing standards for door width and counter dimensions and increase the number of adaptive panels.
While the depth of the trusses will be determined by the design, a few factors must be considered prior. In traditional construction, underlayment such as plywood is used to cover the tops of the joists and provide a surface to attach the flooring. As the adaptive panel cladding would be placed directly on top of the trusses the underlayment cannot be utilized. Since a standard barrier between floors is removed, and both floor and ceiling cladding are removable, this could cause a potential security issue and hazard. To prevent this issue, the “underlayment” would be placed on the bottom side of the trusses to provide a floor-to-floor barrier prohibiting unwanted access (Figure 18). The second consideration is that while not necessary, it is recommended that the trusses be rated for a deflection of L/480. As the panels will be used in a fashion similar to standard raised floor systems, any deflection in the trusses could create a small panel height offset. This would help not only prevent floor panel shifting, but also add to the overall strength of the system.

In the application of adaptable systems support, the trusses support both floor and ceiling loads, therefore truss construction must also consider modular wall system loads. While trusses in traditional construction can be connected to bearing walls through a top chord load support, this assembly is intended to carry loads placed on top of the truss and not for heavy hanging loads. As many adaptive systems designed and discussed in this chapter will act as a hanging load, a top chord load support truss assembly would be insufficient. Thus the trusses should utilize a bottom chord bearing support where the bottom chords are placed directly on top of the wall system or used in conjunction with strong joist hangers (Figure 18).
As the adaptive supporting structure acts as the flooring/ceiling trusses, it also provides the audio barrier between floors. Traditional construction places sound absorbing materials or a double layer of underlayment/drywall to achieve the desired STC. The adaptive support structure is open on top for the floor panels and utilities. In order to prevent airborne sound transmission and vibration through the structure, one potential solution is developed in Figure 19. While the basic construction remains similar to the described prior, additional audio barriers are placed on the bottom chords of the trusses to ensure privacy between floors. Utilizing the deflection criteria, L/480 live load, provides a high degree of resistance against floor vibration, preventing low frequency sound vibrations. To further prevent vibration, a soundmatt can be applied to the top of the trusses where the floor panels make contact. Materials such as rubber or cork may be utilized, but must be thin and rigid enough to prevent panels from significantly dropping lower than adjoining panels when a heavy load is applied. A resilient channel can be applied underneath drywall to lower vibration transfer by minimizing surface area contact. However, in the adaptive support structure, the lowered ceiling support channels accomplish the same function from the support bars. To absorb airborne sounds the underlayment applied underneath the trusses
may be replaced by a piece of sound absorbing rigid foam between two sheets of plywood or similar material. If a higher STC is required, another layer of sound absorbing rigid foam with a plywood or similar material top may be placed between the trusses’ lower chord as seen in Figure 19. This addition can help adaptive utilities placement through truss cavities, as the top of the plywood or similar material could be mounted flush with the top of the lower chord, creating a level surface throughout the cavity.

![Diagram of sound transmission preventative construction method.](image)

\[ \text{STC} \approx 63 \]

**Figure 19: Sound transmission preventative construction method.**

### (4.1.2) CEILING AND WALL SUPPORT

In order to meet adaptable spatial needs, the ceiling support structure is similar to that of traditional suspended ceiling systems. Unlike traditional suspended ceilings that hang from tension wiring, this adaptive ceiling system must bear the weight of ceiling panels and any spatial element utility that hangs from its tracks. As such, the tracks must adequately
transfer weight directly to the main supportive truss system. The additional hanging load is
the rationale for deeper trusses and a bottom chord assembly. A metal spacing bar runs the
length of the trusses and directly attached through the underlayment. The bar acts as a point
for support attachment and guarantee proper spacing of panel supports. Each panel support
is a threaded tube that is thickly gauged to transfer weight and welded directly to the metal
spacer bar attached to the trusses. Each panel is supported by four panel support tubes, one
near each corner along two tracks and secured by wide head bolts that thread directly into the
support tubes via the space in between the panel tracks (Figure 20). During assembly or
removal, a bolt should be halfway threaded to allow for easy placement of the ceiling panels,
and ensure a tight fit.

Figure 20: Adaptive ceiling support system.
(4.2) ADAPTABLE BARRIER SYSTEMS

(4.2.1) ADAPTIVE CLADDING PANELS

As discussed in chapter 3, the spatial barriers define an enclosed space. However, by thinking barriers are floors, ceilings, or walls, and not by what they provide such as privacy, protection, etc… we limit the barrier usage. If a wall is designed solely to act as a wall, the adaptability of such a barrier will never go beyond that of being a wall. Instead, if the barrier was designed to provide privacy, the adaptability potential can be applied towards the floor, ceiling, and/or wall construction. The main cladding option designed for this adaptable system is a panel that has been sized for truss spacing, forming a spatial grid that defines the sizing of all systems. The final design for the standard cladding panel is such that a standardized metal frame can incorporate user selected material(s) attached to either side, and forming a series of support channels when adjoining other panels. For example one side could form a continuous surface or user selected material(s) and be intended for floor or wall usage, while the other gridded channel side, again with user choice material(s) attached, could be intended for ceiling or wall usage. And while the following figures illustrate the surface material as flat and opaque, the options for attachable surface materials are vast but dependent on need. While flatness may be required for flooring for ease of movement by both user and systems such as modular walls, semi-transparent material could be utilized in conjunction with under floor lighting to create diffuse room lighting effect. Panels used for wall cladding could have a textured, layered, wavy, etc… surface material to create a visual striking surface. The only limiting surface materials factors would be the panel frame size and attachment, with the added warning that some surface materials may impede other system usages.
Figure 21: Standard cladding panel frame and surface material attachment diagram.

The standard cladding panel frame is 2 ft. by 2 ft., sized to fit the truss spacing and for ease of handling. As seen in Figure 22, the panels form a track on one side, and maintain a flat plane on the other when adjacent to another panel. The track could be used for supporting mobile or adaptable systems such as modular walls or cabinets when used as ceiling cladding, or shelving when used as wall cladding. The track also helps to hide the panel attachment points, as two of the four panel edges include two ¼ in. radius half circular holes. These points allow for bolts or other panel supports to pass through and secure the panel.

Figure 22: Isometric of two panels forming a full track and support point.
(4.2.2) FLOORING SYSTEM

If users utilize the standard cladding panel as flooring, load support and surface material choice become crucial. While the steel framing of the panel will distribute weight to the trusses without deflection under typical load, the surface material must also withstand typical loading conditions. If considering a 60 PSF live load and 75 PSF dead load, a surface material of ½ in. plywood with veneer (starting from framing center) would sag 0.1 in. under the 75 PSF, but would only sag 0.01 in. if another ½ in. plywood surface material is place on the other side of the frame. While other materials such as hardwoods, plastics, tempered glass, etc. could be utilized, these materials need to be rated prior to usage as flooring.

The second consideration when using the standard cladding panels as flooring is which side of the panel should be utilized. While typically the flat continuous side would create the standard flooring option, users have the option of placing the panels track side up. When used for the typical flat surface option, the panel attachment points may be visible, creating a series of ½ in. holes. As these spaced holes would collect debris if left open, attachment plugs can be placed at these points (Figure 23). If the users choose to place track side up, the tracked flooring option would create the gridded track that could be used in conjunction with other designed adaptable systems. While such systems will not be covered within this thesis, it is the potential for future designers to create such systems.

The standard cladding panel for flooring placement and alignment is as simple as beginning in the corner of a space and working outward. Each panel is the same size and center spaced on supporting trusses, and provides lateral support for surrounding panels. The potential issue for this method is that each panel is not secured in place, resulting in potential hazardous conditions. If security is a user concern, attachment posts can be added to the top of the trusses to rectify the issue (Figure 23). These attachment posts have several advantages. First the placement of standard cladding panels can begin anywhere within the space as the posts have fixed locations. Second the posts provide lateral support, and prevent sliding of panels if an adjacent panel is removed. Third, and as discussed prior, these
attachment posts allow users to secure panels in place with security bolts. These security bolts would prevent unwanted panel removal, but also increase the time needed if change is wanted. For this reason, designers may require the using attachment posts with trusses, but allow users to determine whether or not to use security bolts with their panels.

![Diagram of attachment plug and security bolt options](image)

**Figure 23: Floor cladding attachment post with attachment plug or security bolt option.**

Removal of the panels once placed can be achieved by several methods. A suction-forming device that can easily remove the smooth surfaced panels accompanies typical raised floor systems. While this same panel remover would work on commercial or residential surfaces such as hardwoods or ceramics, it would not work on surfaces like carpeting. The solution is to utilize a panel remover with a strong magnet. As each standard cladding panel has a frame of steel, a magnet could remove the panels regardless of surface material (Figure 24). Once one panel is removed, it would be easy for users to continue removing adjacent panels by hand or continue to use the tools. The tracking edges reduce surface area contact with adjacent panels, aiding in ease the placement and removal of the panels.
The benefit of a paneled floor system over traditional floor systems starts with the users of the space. Traditional systems require permanent installation with chosen materials. However in leasing situations, users are typically without choice of desired surface materials and must either make do or make an agreement with building owners for costly material changes. Paneled flooring however can be removed and replaced by the users. For instance, if hardwood is desired over carpeting, the user can accomplish a simple removal of the carpeted panels and replacement with hardwood panels. Building owners can either have multiple surface material clad panels in storage or require users to purchase their own panels from manufactures and place the removed panels in storage. A benefit to building owners, replacing damaged flooring becomes much easier and less costly for sections that are beyond repair. For example, in apartment buildings, users often have carpeting that could become stained. If a stain cannot be removed, building owners can simply remove the single panel and replace with a new panel. This not only saves building owners or users money by allowing for quick replacement instead of entire flooring replacement, but also maintains user satisfaction. This benefit should be considered by building owners upon panel purchasing so that extra paneling of the exact material can be obtained.
(4.2.3) CEILING SYSTEM

While the surface materials for cladding panels is user defined, panel placement and usage may dictate surface materials. For instance, while the ceiling cladding panels may not need to carry occupants, support of utilities may need to be considered. Also as the space above the ceiling cladding will act as a return air plenum, surface materials should prevent air transfer and if needed, support the attachment of other utilities as will be discussed in the next section. Ceiling materials should not interfere with other adaptable systems, such as modular walls. If the surface material is extruded beyond the panels’ track, users could have difficulty moving modular walls through the space, as the wall may hit the extruding panel surface.

As discussed in the structural section, suspended panel support rods would support the standard cladding panel. The support rods transfer panel weight and hanging systems to the trusses. Beyond weight transfer, the support rods also act as lateral support and panel connection points, similar to the attachment post used for the floor cladding system. As shown in Figure 25, threaded bolts pass through the panels attachment points and into threaded ceiling support rods. While a secured connection does reduce the ease of panel placement and removal, the added time insures safety as the panels support potentially heavy adaptable systems.

Figure 25: Changing ceiling panel instructions.
(4.2.4) WALL SYSTEMS

In chapter 3 the floors, ceiling, and walls were discussed as spatial separators that provided the user with protection, load support, control, and privacy. The adaptability concept allows users to determine the need level and apply them toward the chosen materials for the spatial separators. Wall cladding, unlike floor or ceiling cladding, can have all or none of these features within the context of the interior space. Exterior walls here are inadaptable and users may determine that interior walls are not required. Therefore the level of protection, load support, control, and privacy provided by the wall systems is truly adjustable and contingent on material or assembly. This section will discuss two potential adaptable wall systems, first a rigid option, second being a flexible option.

RIGID WALL SYSTEM

While the standard cladding panel design allows for either floor or ceiling cladding, it can also be utilized as a wall cladding in connection with a supporting structure. As the panels frame itself is steel, any wall systems utilizing these panels to become rigid. The rigid option reflects interior walls qualities by potential load support, control physical movement, and provide security. These qualities and privacy are dependent on user selected materials and assembly. A rigid system however, automatically imparts a level of control and support that a flexible system cannot achieve. If these qualities are required, then a rigid system is a beginning choice for users. Beyond the base levels of control and security provided, material choice dictates the other quality levels. As discussed in chapter 3, transparent materials such as clear plastics could be used with the cladding panel frame to create high levels of security and movement control but have no visual privacy. Users can determine appropriate material choice by understanding principles discussed in chapter 3. It should be noted that users could mix and match material choices to create interesting aesthetics while still controlling the levels within their space. For example, a wood clad panel can be used next to a semi transparent plastic clad panel to create a visually striking line with shifting visual privacy levels.
While floor and ceiling cladding were fixed in place by a supporting structure, a crucial adaptability point for wall systems is to be movable. The supporting structure for the wall cladding must not only support the cladding, but also enable users to move the wall system through the space safely. This external wall system support comes from the track formed by the standard cladding panels. The design relies on the track formed by the standard cladding panels used from ceiling cladding to maintain lateral support of the wall systems and ease of movement throughout the space. The installation of a rigid wall system begins with the structural supporting frame for the standard cladding panels. The rigid wall frame itself is sized to be 4 ft. wide, 8 ft. tall, and 1 in. deep. At this scale, the frame supports eight standard cladding panels per side, and when clad on both sides has a final thickness of around 3 inches. As shown in Figure 26, the rigid wall frame secures panels in a similar fashion to the ceiling and floor systems. Clips and bolts are used at the panel’s attachment points.

Like the ceiling and floor cladding, the wall cladding can form either a flat continuous surface or create the track grid. The track is beneficial to serve as a connection point for adaptable items, such as shelves. During assembly, the panels connect to the rigid wall frame in a similar fashion to that of the ceiling supports, using bolts that pass through the panels connection points and into the threaded holes of the rigid wall frame. The bottom of the rigid wall frame is equipped with ball bearing casters to aid movement of the system, and distribute the weight of the wall system partially to the floor. As the wall system follows the ceiling track, the weight of the wall is often directly under the truss system, and when not, is directly under the metal framing of the ceiling cladding panels to help distribute the weight. When the wall frame is not used it can easily collapse into an 8 ft. by 3 in. by 1 in. bundle while staying connect to the ceiling track. This allows users to easily store wall systems when not in use.
Users that want wall structures to lock in place after positioning for security or load support stability have several locking mechanism options. The following wall lock options are designed to have the locks placed toward the side of the wall system needing to be secured, guaranteeing both intended user control and access. The first potential option could fit within the tracks formed by the wall panels, allowing users to lift a latch prior to moving and secure the latch when the wall system is placed. As this mechanism is small, it can mount flush with the panel faces, but also be quickly added or removed from the wall system with little storage needed. The left image in Figure 26 demonstrates how this type of locking mechanism can provide either a friction hold, or placed over the attachment points of floor cladding panels for added security. The disadvantage to this potential locking mechanism is the requirement of the tracking side of the panel to be utilized. The potential second option is a mechanism built directly into the face of a panel by utilizing panels with utility access cut outs. While similar to the track mounted locking mechanism in application, this option would allow users the choice of exposing the tracking or flush appearance. However, this system has a disadvantage as the panels are locked in place by friction, meaning that unwanted user access could potentially be achieved with enough exerted force on the wall.
system. The right image in Figure 29 illustrates the attachment point and locking procedure for this locking mechanism.

Figure 27: (Left) Track locking mechanism. (Right) Utility outlet attached locking mechanism.

ADAPTABLE DOOR

While adaptable spaces allow users to create separate spaces within an overall area to enhance privacy and security levels by using the various systems discussed in this chapter, an adaptable door system must also be considered. Keeping minimization of components in mind, the proposed door solution uses any adaptable wall system and attachable handle, resulting in a 4 ft. wide sliding door. As the adaptable wall systems are already mobile, a wall system placed in front of the desired entrance point and without obstacles preventing sideways movement, can act as a sliding door. In addition to the adaptable wall system, users could attach handles within the exposed tracks or panel attachment points to aid in sliding the door. The same locking mechanisms can be used to secure adaptable wall systems, could also be used to lock a door in place adding to security and visual privacy. The sliding door could be clad in the same fashion as the surrounding walls, which would create an overall cohesive look and the door would provide little visual intrusion.
If desired, users could set up the sliding door to be flush with the surrounding walls, having to push out and then over to open the door. This method could be used in office spaces where rooms could be closed off when not used or not intended for public access. If the existing tracking created by the ceiling does not align for proper sliding door usage, the addition of a adaptable sliding track can be added, allowing door placement anywhere in the adaptable space. Figure 28 (left) demonstrates the attachment of an adaptable wall system to the additional adaptable sliding track in for a sliding door. Figure 28 (right) shows a rendering of the sliding door blending in with surrounding walls. If users want doors more visually obvious, different surfaced material panels would draw visual attention to any potential sliding door.

![Adaptable Sliding Track and Door Attachment](image1)

**Figure 28:** (Left) Sliding track and door attachment. (Right) Rendering of sliding door.

**FLEXIBLE WALL SYSTEM**

Load support and movement control for a rigid wall option might not always be required. Thus, a second more flexible option may provide users with levels of privacy without additional features. Thus another option is proposed with the ability to create a visual privacy without other separations. Figure 29 below shows a basic curtain to provide visual privacy and the connection from the curtain to the ceiling cladding track. Using “T”
pins that support the rigid wall system, these pins can be connect to the top of the curtain. Suggesting that such spatial separators have one pin every 1 ft. starting with the corners, the user can create curtain walls by connecting the pin to fabric. This way the user can easily create visual privacy with material. As the pins follow the ceiling track, these curtain dividers can even form square corners, as the pins are not directly connected and can follow other channels. Since users can make these separators, length and height are dependent on usage, however 2 ft. intervals are recommended to work in accordance with the grid. If users would like the curtain to be more wall-like, magnets can be sewn into the bottom and edges of the fabric. In this fashion, the curtain could form a flexible wall surface with little sway as the magnets attract to the metal framing of the floor cladding, creating a strong but removable connection. While not in use, this separator can easily be taken down and stored or placed along the exterior walls to form a textured or colored appearance, or simply act like curtains covering windows. If users want high sound control but maintain flexibility in their wall system, the material science company EMPA recently created a lightweight and translucent material similar to a curtain, which can absorb up to 80% of sound. If the curtain-like material was handled in the same fashion as the visual privacy spatial separator, users could create highly audio separated spaces. If used in conjunction with an opaque curtain, users could also create visual and audio separation while still allowing air movement between spaces.

Figure 29: Curtain track connection.
(4.2.5) OTHER SPATIAL SYSTEMS

Beyond the spatial elements created by the ceiling, floor, and walls, other elements can be introduced into the adaptable space that would be part of the spatial situation. This section introduces several adaptable design ideas to work in conjunction with the previously described spatial systems to add to the functionality of the space.

IN-FLOOR STORAGE

Storage is always a concern within a space, whether it is for equipment, clothing, dishes, etc. However an adaptable space requires that storage be either mobile or detached from the space itself. The first option presented is used in conjunction with the standard floor cladding panel. Figure 30 shows how a storage insert can be placed underneath any floor cladding panel, creating storage anywhere within the space but visually and spatially detached. The load is supported directly by the trusses, and the structure fits underneath the gaps formed by the half-track edge. The floor storage insert also allows the floor cladding panel to remain flush. If the storage insert is used, it cannot be used in conjunction with utility supporting panels such as panels with electrical or HVAC outlet points. Also as these in-floor storage containers are placed underneath the floor cladding, users should allow for easy access and/or a visual indication of the storage location. Both access and indication could be provided with a handle installed within the utility access cutout of a panel covering the storage point. As shown in Figure 30 (right image) a handle could be mounted into the same utility cut out that will be used for outlets or HVAC vents, outlined in the next section. To allow modular walls to pass over and avoid tripping hazards, the handle should become flush with the panel top, but be easily grabbed by the user.
ADAPTABLE SPATIAL STORAGE

Adaptable storage spaces can also be added by adapting the rigid wall frame in conjunction with the standard adaptable cladding panels. Figure 31 illustrates the steps needed to create a storage space. As the storage space is defined by panel sizing, it can be made to be 2 ft. or 4 ft. deep, any deeper of a space would be considered a storage room. If 4 ft. depth is decided upon, simply place another panel clad wall system to form the sides. If 2 ft. deep is decided upon, then individual panels can be attached to the side of the wall frame. Once the side of the storage space is connected, the front panels of the wall system can be adapted to meet access needs. Instead of connecting the panels directly to the wall frame, a specialized hinge can be attached to the panel and frame. If multiple panels are required to form a storage door, a track insert can secure adjoining panels, however each panel can act as an individual door and could even potentially open in different directions. Once access is created, handles can be connected to open the storage space while indicating storage points and door swing.
ADAPTABLE COUNTERS AND CABINETRY STORAGE

Yet another storage point, adaptable counters or cabinets add common elements typically present in residential and commercial spaces. While traditional installation requires fixed placement of both counters and cabinets, the designed solution here allows both to be either constantly mobile or semi-fixed in place. The counter would be framed out to be 2 ft. wide by 2 ft. deep. The counters include a flush drawer or cabinet doors with removable handles when applicable, allowing counters to be placed next to each other to form any counter space the user desires. The dimensions are based on the cladding panels used for flooring with the rationale that a floor panel can be removed and the counter taking its place, preventing lateral movement. If the user would like the counters to be constantly mobile, the counters can also be equipped with lockable casters. The height of the counter in this design would be pre-determined, but counters with adjustable height could utilize hydraulics or similar mechanisms. The counter tops would also fit into the 2 ft. by 2 ft. grid, fitted with the standard adaptable cladding panels. If standard cladding panels are used, the counter tops could be quickly removed, cleaned, replaced or exchanged. This method can also be applied to appliances such as under counter refrigerators, or surface mounted electric stovetops. As
these appliances only require electrical access, they could be mounted within the modular
counter and hooked up to outlets after placement. The left image in Figure 32 illustrates
counter movement with casters, inseting into floor cladding for stability, and removable
cladding panel top. The right image in Figure 32 demonstrates how this same counter design
can form multiple counter shapes.

![Figure 32: Adaptive solution counter for placement with cladding panel top.](image)

The formation of overhead cabinets will be similar in construction. Supported by the
ceiling tracks, the cabinets are standard cabinet framed with flush front doors. Dimensions of
the cabinets could vary, but 2 ft. width would be the standard in order to match the counters.
Cabinets are mounted with load supports that connect to the track system of the ceiling
cladding. This cabinet style allows users to quickly move the entire assembly enabling their
use in conjunction with counters or separately. The cabinet weight and its contents will be
supported by the upper tracking system.
ADAPTABLE LOAD SUPPORT

Storage devices such as load supporting bars and shelving can be incorporated to best utilize the storage capacity of the adaptable system. When the track system is exposed and used, it creates a support structure. Figure 33 illustrates how a simple floating shelf can easily be connected to the exposed track of the wall cladding panels while allowing the shelf to be placed anywhere. The shelf is a simple board design, the key element is the track attachment that allows shelf movement when loosened, and secures the shelf support when tightened. While not shown, a load bar such as for hanging clothing can be understood in the same way, using the track system to connect and move the bars placement. These additions are not limited to storage spaces, but also can be redesigned to support other user items such as big screen TV’s. The point of discussing such elements is to demonstrate that adaptability potentials within the space as well as how users could continue to add or change system elements after moving into the space.
Beyond acting as a cladding, the standard cladding panel can also be utilized as surface for counter tops or desks. Similar to the method of connecting floating shelving units, the standard cladding panel can be equipped with a simple load supporting bracket, which attaches to the wall cladding panels track and the surface forming panel(s) tracks. As shown in Figure 35, the load bracket would allow users to raise and lower the panel to the desired surface height while maintaining the grid like structure of the adaptable space. Once the desired height is obtained, users can simply tighten the track guides to secure the brackets.
ADAPTABLE CLADDING PANEL FACING

A final example to demonstrate the potential range of the adaptable system panels can be used to either hide utilities when not in use or create an interesting spatial dynamic. The standard cladding panel frame can be secured to the supporting structure but allow for the surface of the panel to be adjusted by the user, either in height or angle. When lowered, the face of the panel exposes surfaces that can be fitted with utilities such as electrical outlets, speakers, lighting, etc… while maintaining proper sealing for HVAC systems. Figure 36 illustrate two applications of how the adjustable panel surface could be used as utility enclosures.

Figure 35: (Left) Surface panel support bracket assembly. (Right) Render of brackets with panel surfaces.
Figure 36: (Left) Height adjusted panel with lighting. (Right) Angle adjusted panel with speaker.

(4.3) ADAPTABLE UTILITY SYSTEMS

(4.3.1) HVAC

Another benefit to utilizing a raised floor system is the ability to utilize an Under Floor Air Distribution system (UFAD) for the building HVAC. ASHRAE’s 2003 UFAD guide suggests that any building considering a raised floor for cable distribution should consider UFAD. UFAD have not been common in the residential sector so far. With this adaptive system however, there are many UFAD system advantages that can be brought to building occupants and owners. The principle behind UFAD is that the area under the flooring acts as the buildings supply duct instead of a typical overhead ducted system associated with most central forced air HVAC units. As this plenum is part of the flooring system, ducting is not required resulting in both cost reduction and added adaptability. The floor level air supply has advantages over typical forced air overhead supply. With respect to air quality, air is introduced directly into the low levels of an occupied zone instead of the overhead space. As the heated or conditioned air is supplied closer to where users occupy,
the temperature of the supply air can be closer to the desired room temperature as opposed to
the higher heated or conditioned supply air of overhead systems (Figure 37). It has also been
shown that overhead supplies need higher air velocity movement to create a mixing of supply
air with existing air in a room, thus having a higher energy consumption rate. This overhead
supply works on a dilution principal, where supply air dilutes the room’s air to meet desired
temperature levels. The UFAD’s floor supply however does not dilute the air, but replaces it
by forcing out the room’s existing air, providing a fresh and healthy air quality.

![Diagram of forced air overhead HVAC vs. UFAD floor supply](image)

**Figure 37: Forced air vs. UFAD HVAC comparison.**

Beyond the benefits of a UFAD system over typical forced air systems, UFAD
utilizes the spaces already available with the adaptive system. The space provides utility
access under floor panels to accommodate air supply by UFAD, while the lowered ceiling
provides space for the UFAD return air needs. More important is the option for users to
place the vents anywhere they choose in their space as opposed to the static vent locations of
the typical ducted forced air systems. While flexible ducting could be incorporated, the
required equipment needed and space allotment would make potential adaptability
cumbersome for users. As UFAD can work in conjunction with flooring panels fitted with
vents in the utility access cutouts users have direct control over the in-floor vents as opposed
to high level ceiling vents, thus adding to user control and satisfaction (Figure 38). While spaces fitted with UFAD must be monitored for potential air leaks that reduce system efficiency, the parameters of residential spaces would be on a smaller scale than most commercial applications, and have a lower amount of potential air gaps.

Figure 38: Diagram showing a user placing a venting floor panel.

(4.3.2) ELECTRICAL

As mentioned prior, access to electricity within buildings is mandatory by code. From powering other utilities (such as HVAC), appliances, and electrical devices, proper placement of electrical access points becomes crucial to the placement of such devices. Typically, electrical outlets (NEMA 5-15 within the United States) are the primary electrical access points, and the NEC regulates their placement and utilization. As stated in chapter 3, the NEC Article 210.52 dictates minimum outlet spacing. The intention is that no appliance or device needs more than a 6 feet of cord to reach any outlet. However, as the approach for adaptable living and large open spaces, several issues arise for electrical access via electrical wall outlets. In large open spaces, the ratio of floor space to wall length is reduced, thus also reducing the number of the typical wall mounted outlet points. Even if appliances or devices make use of extension cords, outlets numbers would be insufficient as well as creating fire and tripping hazards. Secondly, as interior spaces can be created within the overall space with modular barriers or “walls”, electrical inaccessibility could occur if electrical
adaptability was not applied. While potentially the modular walls could have power directed to them to provide outlet access similar to track lighting, it could pose an electrical hazard to users independently changing either wall or ceiling systems. Another issue, electricity access may be required in the middle of an open space. As the floor cladding is a collection of removable panels, the most practical solution is to place electrical outlets in selected panels with utility access cutouts (Figure 39). This way, users could place panels either near walls for wall based appliances, or in the middle of an open space. As addressed earlier, it is also common for electrical appliances or devices to become grouped together such as for media centers. Thus, the select floor panels could have multiple outlets mounted within one panel. Each outlet should be flush with the face of the flooring panel to allow modular walls to pass over without incident and reduce potential tripping hazards. If however outlets are not required and the panel is needed for flooring, a simple plate could be flush mounted into the utility access cutouts and fill the gap.

The NEC requires all outlets be powered through an over-current protecting circuit breaker, and that all bedroom outlets have an Arc Fault Circuit Interrupter (AFCI)\(^44\). Within adaptable residential spaces such as apartments, every space could potentially be a bedroom,
and thus all outlets should include AFCI. While the electrical outlets for an adaptable space must be modular, they may not act like extension cords and be easily removed from the electrical system. IFC does not allow extension cords usage with major appliances or to act as permanent wiring, because the connection could come loose even with proper extension cord usage, cause arcing or fires. The designed modular electrical outlet for this adaptable system is similar to wall mounted outlets, hardwired into the electrical system using flexible electrical cord (Figure 40).

![Figure 40: Under floor junction box connection to adaptable electrical outlet.](image)

Another potential electrical access, Massachusetts Institute of Technology’s WiTricity project may potentially replace wired electrical outlets in the future. WiTricity utilizes magnetic resonance to create magnetic fields within a space (currently 10 ft. radius) paired with receivers attached to electrical devices, eliminating the need for power cords or batteries. While WiTricity is not currently on the market, the system has been tested, and may hit markets in the near future. If such systems were to be utilized within the adaptable space, it could be simply placed under a floor panel near major electrical activity. Hardwire systems would still be required for major appliances, but the use of electrical outlets overall would be reduced.
(4.3.3) LIGHTING

While lighting is an electrical utility, it has separate building codes regulated by IBC. While lighting is required, within the adaptable space lighting fixtures would not be permanently placed and give users the opportunity to control the lighting conditions of their space. This section will cover two types of potential adaptable lighting fixtures and control methods.

The first adaptable light fixture is developed in conjunction with the standard cladding panel frame. These panel frames already contain removable surface materials, and it only makes sense to utilize the clad system as supports for lighting fixtures. The lighting fixtures can be mounted flush with adjacent cladding panels and easily placed in the ceiling, floor, and interior walls. As shown in Figure 41, a light fixture can be mounted on either side of the panel with a plastic cover or surface material closing off the other side. While shown as a full 2 ft. by 2 ft. fixture, smaller fixtures can easily be attached in a similar fashion in electrical outlets spaces. As the plastic covers are removable and interchangeable, users have the options to alternate opacity, color, and patterns. Users can create interesting lighting experiences within the space through material choice.

Fixtures can be changed and controlled by the user. While several options have been explored, the option put forth here is to control power just prior to the electrical outlet by a wireless switch. These wireless switches are already industry standard for signage. However as multiple lights may require individual controls, these wireless switches can simply be programmed with multiple frequency options. This allows users to define the frequency control and program single or separate units mounted on the wall. Each of the panel mounted lighting fixtures will be equipped with a power cable and an onboard outlet. If the lighting fixture is to be controlled individually, the user can plug the power cord directly into a wireless control switch that connects to an electrical outlet. If a series of lights are controlled, the user connects each lighting fixture power cord to the spatial adjacent lighting
fixtures power outlet, with the final lighting fixture plugged into a wireless switch control and electrical outlet.

![Diagram of potential light fixture standard cladding panel frame connection.](image)

Figure 41: Potential light fixture standard cladding panel frame connection.

If users desire a ceiling suspended light fixture, the ceiling track can act as the fixture support. Either new or retrofitted existing hanging lights, the fixture can have the “T” pin connection point attached in a similar fashion as the flexible curtain wall supports. Placing switch controlled electrical outlets near these hanging light fixtures allow users control in the same fashion as the previously described panel mounted light.

(4.3.4) PLUMBING

Adaptable water supply provides yet another option for adaptable utilities. However, the issue that was raised in Chapter 3 was how much control should be handed over to the user when potential damage to the building could occur. Water removal systems, to include black water systems, can be hazardous when installed and handled by untrained users. Another potential issue is any water supply lines that connect to an adaptable water system for the potential to leak and cause water damage when installed incorrectly. For these
reasons, any applications of adaptable water systems would be limited to commercial spaces with the expectation that maintenance staff would have proper training. Within residential spaces, it is recommended that water usage systems be permanently installed, best placed near exterior walls or within a non-adaptable space.

With that limitation in mind, adaptable water supply has been successfully applied outside of integrated architectural applications. High pressure water systems such as high pressure washers utilize water tight, quick-connect, highly durable, and flexible water supply hoses. With these hose and connection types, commercial buildings could incorporate water outlet points with shut off valves around the exterior of the adaptable space. Trained users could attach quick-connect adaptable hose(s) to the supply point and run it through the utility cavity to the water outlet built into adaptable systems. Once connected, the supply shut off valve can be turned on to allow water flow, and outlet point turned on to remove air from the line.

Unlike the adaptable water supply, adaptable water removal or drainage is much more complicated, and has a greater hazard risk, especially when black water systems are considered. The issue beyond potential leakage is achieving adequate drainage. Any adaptable drainage system would have to be flexible in order to reach and attach to the structure that needs to be drained. As such, creating an incline to promote natural water movement within the length of the drainage hose becomes difficult. The solution is to create mechanical induced water movement by lower pressure creation within the drainage hose to the exterior space outlet point. This suction helps to drainage hose evacuation, but also prevent unwanted smells from escaping the system. To simplify the operation, the device requires drainage seals at the hose connection point when not draining. If an exterior water drainage outlet point is not used, and the hose is disconnected, the outlet could be capped.

(4.3.5) OTHER UTILITY SYSTEMS

Beyond the basic utilities considered so far, users may require other utilities such as cable (TV and internet) connections, local area network phone connections, etc… in the
space. These connection outlets and methods have a similar principle and installation to the electrical outlets. Each adaptable space will provide these utilities junction boxes along the exterior walls in the same way as the electrical outlets. However, unlike electrical outlets that provide only one utility per outlet, these types of utilities have traditionally been lumped together within the same outlet box. As wireless technology has allowed for these utilities to be placed far from usage, it is practical to continue to allow for multiple utility connections to remain within the same outlet box. Users then can place these outlets in areas of immediate utility usage or in storage areas for utility devices.
CHAPTER 5: APPLICATION

While the previous chapter covered the individual adaptable systems, and their interconnectivity with adjacent systems, the benefits and rationale for these systems only become apparent when their applications are demonstrated and discussed. Thus this chapter not only demonstrates and discusses the applications of adaptable systems within a defined space, but also scenarios that would require spatial changes.

(5.1) POTENTIAL USAGE APPLICATION

In order to best demonstrate the systems in use, this section is based upon a user profile, needs, and a given space. The space will be adapted to meet situational needs in different scenarios to demonstrate how the adaptable systems can be used to create a functional space.

(5.1.1) INDIVIDUAL USER PROFILE

Before demonstrating “how” the adaptable space is being setup and used, the “why” of the adaptable space must be addressed. This “why” is dependent on the user, and as discussed in chapter one, could be different for every individual that utilizes a space. Therefore an example user profile has been created in order to give a background understanding of why this particular user is occupying an adaptable space, what his/her particular needs, and how the space and systems will be utilized. The following user profile defines a user, location, occupation, and gives background information and why he/she has chosen an adaptable space.

NAME: Lee Ireland

LOCATION: Boston, Massachusetts

OCUPATION: Freelance Architect
BACKGROUND: Lee is a recent graduate of Iowa State University with a professional Bachelors degree in Architecture. He has since returned to his hometown of Boston, Massachusetts. Positions for architectural interns are scarce during the current economic downturn, and Lee has decided to become a freelance architectural designer for firms in need of temporary help and individual residential clients. As large apartments in Boston are expensive, Lee has decided to rent an adaptable apartment within a newly renovated brownstone project, with minimal square footage needs, as has allowed him to alter the space.

USER NEEDS: Beyond living in the space alone, Lee expects to work and entertain guests or clients. His particular needs must accommodate the typical bed, bath, kitchen, dining, and living room but also a workspace, meeting space, and ample storage. Lee understands that as long as the space and adaptable systems can form the required spaces, that they do not necessarily have to be formed all at once, but formed as time unfolds.

(5.1.2) SPATIAL PROFILE

Just as it is important to define particular users and their spatial needs, it is also important to define the particular space they will be operating in. This section defines the profile of an adaptable space developed based on basic needs as defined by the user. The following information is the spatial profile, and is followed by a layout of the space (Figure 42), and a rational for these particular spatial presets.

APARTMENT SIZE: 32 ft. by 20 ft. or 640 ft² to include 520 ft² of open adaptable space.

NON-ADAPTABLE ELEMENTS:

- 55 ft² Bathroom
  - Walk in shower
  - Sink with drawer basin
  - Toilet
  - Storage space
• Kitchen Space
  o Sink
• 50 ft² Mechanical/Laundry/System Storage Space
  o Stacked washer / dryer
  o In-line water heater
  o Electric furnace
  o Adaptable system storage
• ≈150 ft² South facing glass

Figure 42: Open adaptable apartment space plan.

The grid pattern represents the 2 ft. by 2 ft. grid formed by the standard cladding panels used for both floor and ceiling. Within the adaptable space, a single sink with surrounding counter space is provided and not adaptable. As mentioned in chapter 4, while adaptable plumbing systems are possible in residential applications, they are only recommended for use in commercial spaces. For the same rationale, the apartment also includes an inadaptable bathroom with shower, toilet, sink, and some storage. Next to this bathroom space, the mechanical/utility room provides the space for mechanical systems, laundry, and storage for adaptable systems. The windows of the space are floor to ceiling on the south wall of the apartment, which is an ideal scenario. The amount and placement of the windows for this space are to allow users to define window “placement”
with adaptable wall systems that could cover windows, but also to allow for passive solar heating. The windows also on the same 2 ft. grid as the internal space to add visual interest and a grid cohesion with the space. The entrance is located on the west wall, with entry just north of the kitchen sink.

(5.1.3) POTENTIAL USAGE AND SPATIAL LAYOUTS

Given those specifics of the user and his space, scenarios can be created to demonstrate how adaptable systems can come together and form a desired space. This sub-section is broken down into several usage scenarios and the potential layouts that can be formed to meet the spatial needs of the situation. These scenarios are intended to demonstrate the adaptability of the space, but also to help visualize the adaptable space in use. However, it should be noted that the following scenarios, layouts, and material choices are just a small fraction of possibilities and meant to show response to a particular user’s choice.

USAGE SCENARIO #1: GENERAL SUMMER USAGE FOR EVERYDAY LIVING

As the space has an entire bank of exterior floor to ceiling windows, this setup must control the amount of natural light entering the space, as the sunlight could quickly overheat the space during warmer months. This setup also incorporates the users spatial needs for sleeping, cooking, dining, media viewing, and working, but not necessarily all at once. Beyond these typical living spaces, Lee requires a space dedicated to work and ample storage for his personal and work belongings. The following information includes user defined spatial and utility needs, a potential layout, and a rationale.

SPATIAL NEEDS:

• Single Closed Bedroom
  o Queen bed
  o Night stand
  o Clothing storage
• Moderate Sized Living Room
  o Media center
  o Seating
• Moderate Sized Office Space
  o Desk
  o Shelving
  o Storage
• Small Dining Space

UTILITY NEEDS:

• Media Outlet(s)
  o Living room
• Internet Outlet(s)
  o Office
• General Electrical Outlets
• Minimized Windows

SPATIAL LAYOUT # 1

Figure 43: Typical summer layout.

Figure 43 illustrates a potential layout within the provided space that meets all of the users general living needs during the summer months. The northwest corner has been arranged with two love seats and end table that sit across from an adaptable wall system mounted with his television and entertainment shelving. This living room space also provides the majority of electrical outlets, as most electronics will be placed within this space and seen rendered in Figure 44. The kitchen space forms around the sink in the
southwest corner of the apartment. The adaptable counters house the kitchen appliances such as a cook top, and small refrigerator, all of which are partially blocking incoming natural light to prevent spatial overheating. The dining space is formed in the southeast corner with the placement of adaptable furniture, such as 2 ft. by 2 ft. table structures that form a long single side-sitting table. This placement partially blocks incoming natural light, allows the user to sit and eat while having a direct view outside. The bedroom and workspace is formed in the northeast corner, becoming private with the enclosing adaptable wall systems and sliding adaptable door as seen in Figure 45. The bed shown in the spatial plan is a Murphy bed, which creates a desk space for the user to work at when not used for sleeping. In-floor storage, and floor to ceiling storage has been created with the respective adaptive systems. HVAC and lighting panels have been placed centrally within each defined space to meet the user’s general needs. The following spatial renders show the same spatial arrangement with potential surface materials and user patterns.

![Image](image.png)

**Figure 44: Renderings of typical summer layout (Living room).**
USAGE SCENARIO #2: GENERAL WINTER USAGE FOR EVERYDAY LIVING

The general winter setup for everyday living is developed for October thru March. Unlike the summer months, Lee takes advantage of the floor to ceiling bank of windows for natural passive solar heating allowing light in the space. Lee arranges the HVAC inlet and outlet points to help promote a convective loop, and places phase change materials he has purchased separately under the floor for thermal mass. Just like the summer setup, Lee still needs a space for sleeping, cooking, dining, and living, but not necessarily all at once. Again, Lee still requires a space dedicated to work and ample storage for his personal and work belongings. The following information includes spatial and utility needs, and the potential layout, as well as the rationale for the layout.
SPATIAL NEEDS:

• Single Closed Bedroom
  o Clothing storage
• Moderate Sized Living Room
  o Media center
  o Seating
• Moderate Sized Office Space
  o Desk
  o Shelving
  o Storage
• Small Dining Space
• General Storage
• Maximized Window Opening

UTILITY NEEDS:

• Media Outlet(s)
  o Living room
• Internet Outlet(s)
  o Office
• General Electrical Outlets
• General lighting
• General HVAC

SPATIAL LAYOUT# 2

Figure 46: Potential winter arrangement.

The general winter layout is very similar to that of the general summer layout (Figure 46). Because the requirements are the same apart from the variation of window
usage, and thus the user can quickly change between the two settings. The major difference of course is that the adaptable counters, cabinets, and tables are pulled away from the south facing windows in order to allow for more direct sunlight to enter. As mentioned prior, the HVAC outlets and inlets are no longer centrally located and placed at opposite ends of the space to help create a convective loop that moves the solar warmed air through phase change materials. The thermal mass under the floor cladding stores heat during the day, and releases the heat back into the space at night. However, to accommodate slight special changes, the bedroom wall has been pushed in by 2 ft., reducing the bedroom and storage space. As mentioned in the summer layout section, this bedroom space acts as the users work area, as the Murphy bed doubles as a desk.

**USAGE SCENARIO #3: SOCIAL DINNER EVENT / CLIENT MEETING**

Beyond Lee’s living and working space, the adaptable space should also be able to accommodate guests for dinner events or client meetings. The same arrangement can be used for both events, as the requirements for both events can be met with a similar configuration. His more private spaces, such as his bedroom, should not be visible and he must gear the spatial apartment toward a more open and engaging environment. Spatially the apartment must accommodate a seating space for six, a large meeting space with potential for a projection surface, direct restroom access, and closed off or removed private spaces. Utility requirements include meeting the light and HVAC needs for the spaces and six people, readily available electrical and media connections for laptops, music, and/or projector hookups. If guests are over during the day, the natural light coming into the space should be controllable for projection needs. The following information includes spatial and utility needs, a potential layout, and a rationale for the layout.
SPATIAL NEEDS:

- Large Gathering Space
- Large Dining Space
  - Seating for six
- Large Kitchen Space
- Direct Restroom Access

UTILITY NEEDS:

- Speaker Outlets
- Heavy Lighting
  - With dimming control
- Heavy HVAC

SPATIAL LAYOUT # 3

Figure 47: Potential social event or client meeting layout.

Figure 47 illustrates a potential layout that meets those spatial user needs for several dinner guests or client meetings. The living room space has been arranged for seating across from each other for easy communication, along with the end table and television placed for computer support and display. The outlets of the space have been placed conveniently for media support but without a tripping hazard. The dining space has been converted into a large kitchen table or conference table for guests to sit for their respective use. Adaptive wall systems have been placed to block incoming natural light.
for internal light control and form a projection wall for presentations. The bedroom space has been removed by storing the adaptive walls and storage into the mechanical/utility room. Under-floor storage is also now accessible as the bed is raised to form a work desk space, also allowing for restroom access. Lighting and HVAC have been placed in major guest gathering areas to help meet the increased occupancy. The following renderings (Figure 48 and 49) show how the same space would look with this arrangement.

**Figure 48: Renderings of social event or client meeting space (Gathering space).**

**Figure 49: Renderings of social event or client meeting space (Meeting space).**
USAGE SCENARIO #4: VISITING FAMILY/FRIENDS

On occasion, Lee will have friends and family come to visit him in Boston. Instead of asking them stay at a hotel, thus limiting the time he could spend with them, Lee can adapt his apartment for guests. The extra guests mean the addition of an extra sleeping space, reduced master bedroom, guest storage, and increased public spaces. Utilities must also be increased and placed near the private spaces for the guests in order to meet their utility needs such as electricity. The following information includes user request for this scenario, a potential layout, and a rationale for the layout.

SPATIAL NEEDS:

- 2 Private Bedrooms
  - Bathroom access
  - Storage (not just floor)
- Moderate Living Room
  - Seating for four
- Moderate Dining Space
  - Seating and surface for four

SPATIAL LAYOUT # 4

Figure 50: Potential overnight guest layout.

UTILITY NEEDS:

- Media Outlets
- Electrical Outlets
  - For each room
- General Lighting
  - Controllable for each room
- Moderate HVAC
Figure 50 illustrates a potential layout to accommodate an overnight guest. While similar to the general living layout, the living room space has been enclosed with adaptive wall systems and adaptive sliding door to provide the guest privacy during their stay. The loveseat typically used for seating folds out to form the guest bed, with the end table now a nightstand. The bedroom walls have been pushed out and now adapted to allow restroom access directly to the guests while maintaining the privacy of the user. Kitchen and dining spaces remain the same, as usage remains functional for the added occupancy. HVAC and lighting have been altered to meet the new spatial configuration. The rendering in Figure 51 illustrates the spatial alterations and surface changes for overnight guests.

![Figure 51](image)

**Figure 51: Rendering of overnight guest space.**

**USAGE SCENARIO #5: MEDIA VIEWING EVENTS**

Beyond architecture, Lee also enjoys watching movies and Boston Red Socks games, both of which he enjoys in the company of friends and family. As such, the general living room space is not adequately set up for several guests, and as food and beverages are commonly consumed during these occasions. The dining space should also be able to view
the games or movies. The layout for that scenario would be similar to having guests over for meetings. The private spaces should be removed or minimized from view while allowing direct access to the restroom. The following information includes user defined spatial and utility needs, a potential layout, and a rationale for the layout.

SPATIAL NEEDS:

• Large Media Room
  • Seating for four
• Dining Space with Media Viewing
  • Seating and surface for six
• General Kitchen Space

UTILITY NEEDS:

• Media Outlets
• Direct Restroom Access
• Direct Access to Refrigerator

SPATIAL LAYOUT #5

Figure 52 illustrates a potential layout to meet the needs of the user’s and guests during a media-viewing event. The living room space of the typical layout has been replaced with the counters of the kitchen space. This space now has become the staging area for snacks and direct refrigerator access. The living room furniture and adaptive wall systems with the entertainment system have been moved to the southeast corner to replace the dining
space. This arrangement allows for comfortable seating and viewing of the TV or projection screen. The adaptive table has been moved to behind the loveseats, providing additional seating but with a surface for eating or beverage placement and providing direct media viewing. The bedroom space has been collapsed and moved to remove private spaces and direct access to the restroom. The rendering in Figure 53 illustrates the appearance of the space to include arrangement and surface materials for this layout.
SUMMATION

The goal of this thesis was to address several issues related to current architectural practices. The first issue was the staggering waste production related to construction, renovation, and demolition of buildings, producing nearly 210 million tons of waste a year in the U.S. alone and rising. Current architectural building practices are quickly filling our landfills. Worse, many buildings are being renovated or demolished prematurely due to changing spatial and utility demands. The second issue is a related architectural concern, just as renovation and demolition waste is related to changing user demands, traditional construction methods limit users ability to control the spatial and utility aspects of their architectural spaces.

By understanding these issues, the second chapter examined prior designs that have attempted to provide solutions to one or both issues. The first section focused on solutions addressing the waste production directly. The Netherlands has attempted to directly deal with the rising architectural waste by providing support to designers attempting to prevent construction, renovation, and demolition waste production. The multiple groups provided several solutions and methods, however, each focused on providing flexibility within the architectural space. The flexibility provided by each solution was in attempt to create an architectural space that could continually meet changing users spatial and utility demands. The second section focused on design solutions addressing the control of the user over their space. While the first section provided more typical solutions, the second section includes solutions intended to inspire designers and users alike. For instance, the designers Archigram illustrated the architectural potential of a space that could continually relocate and interact with other dwellings forming walking cities. While purely conceptual, the same section illustrated modern N55 designers that have developed an actual interpretation of the walking city to form a walking dwelling that can nest with other dwellings. Taking from the ideas presented, a solution to both architectural issues began to form as a space that is completely adaptable.
If a completely adaptable space was to be realized, the user spatial and utility requirements needed to be analyzed in order to develop a working spatial solution. The third chapter was developed and broken into separate spatial and utility needs to better understanding them individually. Spatial elements are simply spatial definers and dividers, all to be understood as potentially providing the user with the similar needs. These spatial barriers must meet the users need for protection and/or privacy. Protection was defined as providing a physical divider of climate, physical load support, and movement control. Privacy separators, either physical or implied, that provide users separation of vision, audio, and olfactory elements. The chapter also covered the climate control, user support, and convenience utility elements of the space, discussing both typical applications and issues. As climate provides the utility comfort elements of space, including HVAC systems. Utilities that require non-climate support such as plumbing, lighting, and electricity were discussed, addressing the importance of placement, and the issues of typical applications. Finally this chapter discussed the non-essential convenience utilities such as media utilities that influence the spatial arrangement of a space, and how typical application reduces the users spatial control.

Understanding the architectural issue, previous solution attempts, and user spatial/utility needs, an architectural spatial solution was developed. This solution took the form of an adaptable spatial system that allows for modular and interchangeable user controlled spatial and utility elements. As the proposed adaptable solution can be easily installed, removed, spatially controlled, and pre-manufactured, it potentially reduces renovation, and demolition waste while allowing user spatial and utility control. The proposed system was discussed in three sections, system support, spatial elements, and utility elements. The support section discussed the needed built-in support structures and limitations of the space for users and the adaptable systems. The spatial section introduces how the spatial barriers of the space can be realized as the same cladding, adding not only to adaptability, but also interchangeability of all surfaces of the space. Also illustrated was how to form surfaces and spatial definers with just the cladding or by included separate modular cladding supports. Lastly, the utility section discussed how utilities can be placed throughout
the space to meet user needs, but also the ease of adding such utility access.

While the proposed adaptable design provided a solution for the established architectural issues, the solution is best understood with discussion and illustration of the designs application. The final chapter established a profile for a user, a space, and scenarios that would require spatial change in order to demonstrate how the adaptable system could be utilized. Along with these demonstrations, spatial layouts and renderings were provided to visualize potential spaces created by the adaptable systems.

As this summation outlines, the architectural issues have been addressed, researched, understood, solved, and applied. The final result is a product that could potentially be taken to market and applied to construction to form the described space. With these designs applied properly in real world application, this thesis product would reduce the aforementioned waste while providing needed user control over their architectural space. As such, this thesis may potentially represent a step forward in architecture, providing not only stylistic change, but also potential change how users see and interact with their architectural surroundings.
LIST OF FIGURES AND SOURCING


2. Referencing Project Flexible Breakthrough (LEFT) Image after the removal of load bearing wall. (RIGHT) Image after installation of steel supporting frame.
   Source: Nico A. Hendriks, Haico van Nunen and Paul G.S. Rutten; Application of IFD Technology to existing Apartment Buildings.

3. MeroForm M12 Node and Tube Connections.
   Source: http://www.systemsxl.com/systems/m12/meroform_m12_m6/meroform_m12_m6_exhibition_system.htm#nogo

4. MeroForm M12 Panel Clip (Left), M12 Spider Connector (Right).
   Source: http://www.leo-exhibitions.com/assets/m12-download.pdf

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2. STC Levels and Occupant Hearing Capacity.
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ENDNOTES


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5 Debacker, Henrotay, De Temmerman, De Wilde, and H. Hendrickx. "Introducing Adaptability in Existing Residential Buildings through Reuse and Disassembly Strategies for Retrofitting." (Pg. 22)


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