Design Strategies for New and Renovation Construction that Increase the Capacity of Buildings to Accommodate Change

by

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ABSTRACT

An analytical framework is developed for examining the critical characteristics of design strategies for new and renovation construction that increase the capacity of buildings to accommodate change, and for selecting appropriate design strategies for particular projects. Unlike previous building studies, this research explicitly takes into account the interactions within and between building systems and subsystems that affect the capacity of the building to accommodate change.

A sample of 37 unique design strategies is identified through interviews with construction industry professionals and a review of recent literature. All design strategies and data are empirically derived and have been used in one or more buildings throughout the world. The achievements of design strategies are compared to the needs of users, to identify strategies that successfully fulfill the building user's needs over time. These achievements and needs are consistently characterized in matrix form, accounting for types of changes expected, enhanced, or enabled, building systems affected, and timeframe of expected changes. Benefits of each design strategy are evaluated over the full life of a building. Strategies with common means of increasing systems' capacities to accommodate change are compared and contrasted. Several strategies are recommended for particular building types, and for three individual case study buildings.

Application of the analytical framework provides new insight into the nature of changes needed in different types of facilities, and the variety and applicability of means to achieve those changes. A building designer or facility manager could use this framework to properly select one or more design strategies that would satisfy the needs set forth by an owner for a particular project.

Thesis Supervisor: E. Sarah Slaughter
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1 Problem Statement

1.1 Change in Buildings

The need for flexibility in the design and construction of buildings is reflected in the large amount of change that buildings experience over their lifecycle. These changes range from minor rearrangement of interior finish systems to large-scale "gut-and-replace" renovations to the addition of new levels atop existing structures. Changes may occur for any number of reasons, including the need to reconfigure space to improve the flow of people or products through a building, a desire for new services and equipment, and the accommodation of new users and usage classes. These changes may be difficult to predict at the time of initial construction, when design alternatives could be considered that could more easily accommodate the anticipated changes.

Currently, the annual construction market in the United States represents over 4% of the U.S. Gross Domestic Product, with expenditures of about $665 billion, of which 80% ($540 billion) is spent on buildings (U.S. Census Bureau, 1999). During the last decade in the United States more than half of the total building construction expenditures have gone to some form of renovation, remodeling, or reutilization of existing buildings (Lee and Aktan, 1997). Clearly, the upgrade and rehabilitation of existing buildings is of significant importance to the U.S. construction industry.

1.1.1 Performance Standards and Building Deterioration

Building occupants and owners are often quite sophisticated when it comes to the performance of their buildings and building systems, and many are requiring that buildings achieve certain performance standards. Performance standards are based on the actual physical characteristics and functions of a use – their 'performance' – measured against pre-determined criteria and standards (Goldin, 1995). For example, a building occupant or owner may require that a particular occupied space be kept within certain temperature levels, without exceeding a certain cost. When an HVAC system fails to provide enough heating or cooling air to the space, or becomes too old and expensive to operate affordably, the system no longer meets performance standards and actions must be taken to remedy the situation (e.g., repair or replace the HVAC equipment).

Building obsolescence is not a matter of design alone, but must be considered within the context of a facility's entire life cycle, from initial planning through operations and maintenance (Iselin and Lemer, 1993). Even the best-designed systems will deteriorate into obsolescence when not properly maintained. When a system does become obsolete, some action must be taken to repair, upgrade, replace, or dispose of the system and/or system components. Whether or not a facility is designed to accommodate these changes can have large impacts on the associated costs. Obsolescence can be forestalled by addressing occurring obsolescence, and by retrofitting or reusing facilities to minimize the costs of obsolescence (Iselin and Lemer, 1993). Obsolescence can also be forestalled by making flexibility an explicit goal, and making appropriate use of design details or integrated building systems that enhance flexibility or adaptability (Iselin and Lemer, 1993).

1.1.2 User Needs Change with Time

In a world where technologies are constantly changing, it becomes very difficult for building owners and occupants to clearly see the changes that may have significant impacts on their respective needs. Some planning for anticipated changes can be done easily, especially for those changes that are expected in the very near term. Other changes may be more uncertain, but anticipated in the light of predicted technological advances in the next few years.

Some needs are specific to the current building usage class or to the activities of the current building occupant type. The adaptability of office building layouts is becoming a major concern of building users (Patterson, 1999; Anderson, 1988; Vangen, 1999). Laboratory buildings must be able to adapt in the size of individual laboratories, without excluding critical services, as well as be able to absorb new services as technological advances occur (Raiford, 1998). School facilities need to be flexible for wiring changes and wall realignments, because it is difficult to predict the technologies that will be incorporated throughout a school's long life (Patterson, 1997). Retail stores frequently create new displays, each of which may have unique lighting needs. New or changing layouts within the store may require new configurations of finish systems and environmental systems (i.e. diffusers that will not blow directly on customers) (Green, 1986). Medical facilities face changes in information technology systems, for managing both administrative chores and clinical information. Computer terminals increasingly appear in all areas of medical facilities, creating wiring and rewiring needs for changing loads and technology upgrades (Valins, 1993).

Other changes occur with respect to a change in a building's usage class. A study completed by Christopher Maury (1999) identified 26 building projects, including industrial, retail, office, research & development, institutional, and residential buildings, which underwent renovation.

After completion of the renovations, fifteen of the 26 buildings had changed from one usage class to another. When a building experiences a change of usage class, a major renovation is typically undertaken, in which building systems may be stripped out completely and replaced with new systems to meet the needs of new users and tasks. Entire buildings may be stripped down to the bare structure and essentially rebuilt around it. These changes may be very difficult to discern and accommodate before they actually take place, especially if the new usage class is unknown.

1.2 The Running Costs of Buildings

The term of building ownership varies greatly throughout the industry. Developers of speculative space create buildings for the purpose of selling them off quickly, often within 5 or fewer years. Institutions such as universities, governments, and religious organizations may own buildings for ten or more decades. Whether the building is owned for a short time or a long time, the ability to accommodate future changes can be an important and valuable feature of a building; an institutional owner requires a building that will adapt to its future need changes, while a short-term owner can sell that ability as a value added to the next building owner. Many building owners believe that in order for a building to accept future changes it must be overbuilt, or that the extra investment in construction materials could simply be added later, when a decision for expansion is made. Another belief is that investing in systems that make future changes easier to implement cannot yield significant future savings. Thirdly, owners often evaluate buildings on the initial costs of construction, without evaluating the running costs, such as energy savings, operations and maintenance expenses, upgrades, and system replacement and/or demolition costs.

In the construction industry, there is much misunderstanding about the magnitude of capital investments dedicated to the different building systems over time. Traditional views of building costs do not include operations and maintenance or the cost of future upgrades, because owners frequently think of these costs as negligible. Figure 1.1 shows that this is often not the case. In the course of 50 years, the total capital costs spent of service upgrades and space plan rearrangements can greatly outweigh the cost of the structure, and even outweigh the total cost of initial construction.

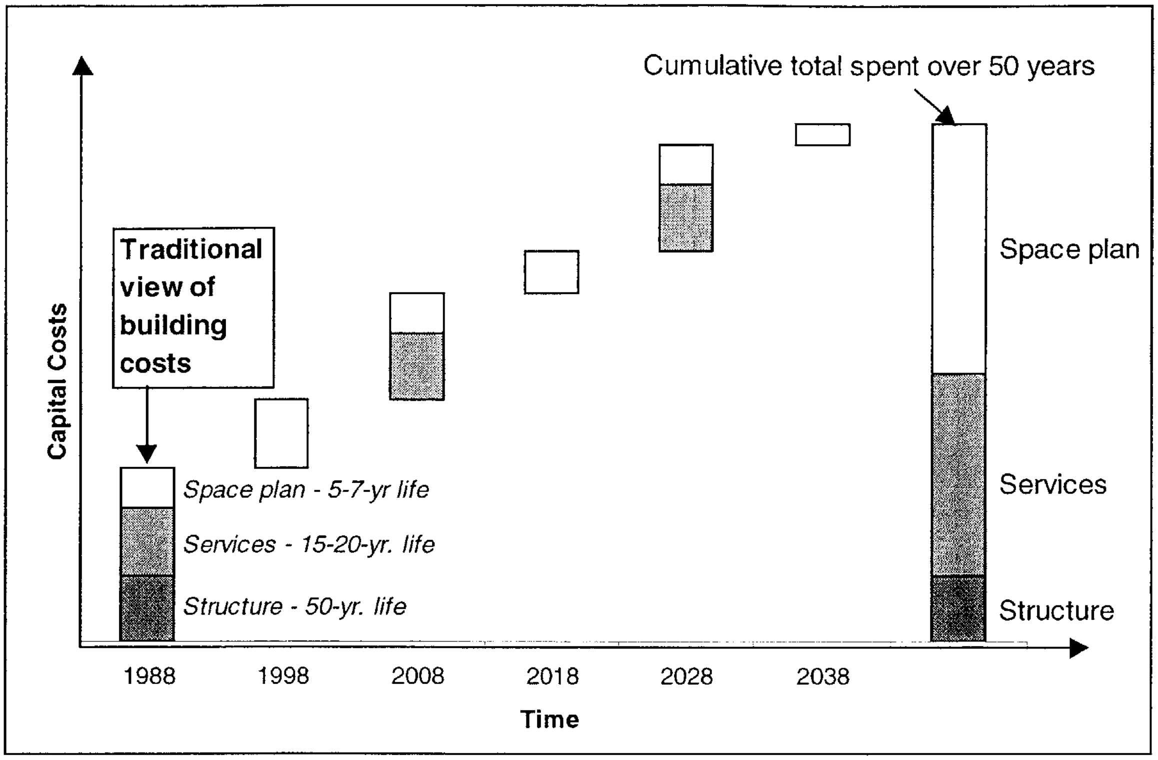


Figure 1.1 – Model of the Running Costs of Buildings: "Add up what happens when capital is invested over a fifty-year period: the Structure expenditure is overwhelmed by the cumulative financial consequences of three generations of Services and ten generations of Space plan changes." (Duffy, 1990; Brand, 1994)

1.3 Research objective

The objective of this research was to identify and analyze the approaches and strategies involved in the design and construction of built facilities that explicitly take into account changing needs over a given facility's life. It is important to note that all strategies identified in this research are empirical, derived from observation of their use on actual building projects throughout the world.

The objective was achieved in five steps. First, a review was conducted to identify and examine previous research examining flexibility, design strategies, the factors that affect the success or failure of given designs, and methods of measuring and evaluating these characteristics. Second, the critical characteristics of design strategies were identified, and an evaluation framework was developed to aid in the selection of appropriate design strategies for particular projects. Third, owners, developers, and designers were contacted to help identify design strategies that are used to increase a building's capacity to accommodate change. Several projects were identified that incorporated these strategies, from which the design strategies were extracted. Fourth the critical characteristics of the full sample of design strategies were analyzed. Finally, the strategies were grouped into clusters by their common general means of achieving flexibility in a system, and each cluster of strategies was examined for common trends in the data.

The framework developed in this research can be used by building owners, developers, and designers to aid in determining the appropriate design strategies for the design and construction of a particular building. The sample of design strategies is large enough to indicate trends in the data that allow design strategy alternatives to be quickly screened for their expected applicability for the given project.

1.4 Thesis Organization

Chapter 2 outlines the background of the changes a building might experience throughout its lifecycle, citing specific references from relevant literature. Types of renovation construction are examined, followed by a discussion of building performance standards and models of building systems, and designing for flexibility.

Chapter 3 describes the five-step framework for the analysis, as well as the expected findings. Each step in the framework is discussed in detail, addressing the applicability, feasibility, and value of design strategies.

In Chapter 4, the data collection methodology is described. Data sources are reviewed and the full sets of projects and design strategies are presented.

Chapter 5 presents the results of the data analysis, comparing and contrasting the actual findings to those that were expected. Results are first presented for the full sample of design strategies, followed by the trends observed in the results of the analysis of each cluster of strategies.

In Chapter 6, conclusions of the research are made, and recommendations are made for further research into this topic.

2 Background and Literature Review

2.1 Buildings as a Long-term Asset

The provision of functional space by rehabilitating old, outdated buildings, rather than constructing new ones, has become increasingly popular with developers for many reasons. Since the building boom of the 1980's, renovation construction activity has been growing steadily, continuing to do so even while new-construction activity was decreasing (Kiell, 1992). Within many urban areas, the value of existing, older buildings is rising, as the economics of renovation appear to be more favorable than the economics of new construction (Lee and Aktan, 1997).

Like other assets, buildings are designed to last a finite period of time. A building's value changes with time and other factors. As the value of these buildings change with time, the needs the owner and/or user have, which the building should fulfill, also change. The asset (i.e., building) must be periodically evaluated on the basis of new, and future (defined) needs, and the ability of the asset to fulfill those needs. Potentially, there are three ways in which the needs of the user may exceed the capacity of the asset to fulfill those needs: (1) the ability of the asset to fulfill certain needs has degraded, while the actual need has not changed; (2) the needs of the user have changed, while the ability of the asset to fulfill the initial needs has not degraded; (3) given that the ability of the asset to fulfill certain needs has changed, and the capacity to fulfill the initial needs has degraded, the value of the asset must be reevaluated (Stewart, 1997).

Three possible results to the outcome of the evaluation may be possible. First, nothing may be done until the needs are more clearly defined. Second, the asset may be disposed of or sold at salvage value. Third, the asset can be renovated or repaired to meet the defined need (Stewart, 1997). A fourth possibility exists, in which the asset can be used to fulfill some other need, and the defined needs can be fulfilled in some other manner.

2.1.1 Renovation and Adaptive Reuse

The terms "renovate" and "reuse" are general words that are often substituted for other terminology more specific to the tasks involved in a given project. Other frequently used terms include rehabilitation, reconfiguration, restoration, modernization, retrofit, conversion, facelift, and refurbishment. The variations in these terms become important in specifying the more detailed aspects of a renovation project. Generally, "renovation" refers to a re-creation, to some degree, to make an existing facility more accommodating to the needs of its users. "Reuse" implies renovating for a change in a building's usage class—from a warehouse to an office building, for instance, or from a distribution center to an R&D industrial park (Kiell, 1992).

2.1.2 Why Renovate or Reuse Buildings?

"In general, renovation can have many benefits, including increasing rents, lowering vacancy, lowering operating expenses, and increasing future property value" (Brueggman and Fisher, 1997). On some occasions, rehabilitating older buildings may qualify owners for specific tax benefits (e.g., a 20% tax deduction on construction costs for buildings on the National Register of Historic Places, or a 30% tax credit for renovations of industrial buildings for a new industrial use) (Campbell, 1996). Most reasons for renovation can be attributed to the specific advantages that can be gained by opting for rehabilitation and re-use (some of which are listed in Table 2.1), although in some cases there may be legislative constraints which leave a developer no choice but to re-use an existing building (Highfield, 1987).

• The availability and/or quality of raw material to be reused
• A shortened development period
• The economic advantages, including tax credits and lower development and/or finance costs
• The availability of financial aid from rehabilitation grants
• The planning advantages (e.g., planning permission may not be required, new codes may prohibit development of buildings with high plot-to-area ratios, etc.)
• The architectural advantages (e.g., components constructed by skilled craftsmen using high quality natural materials, located in close proximity to other architecturally attractive old buildings)
• The availability of existing infrastructure (e.g., shared roads, street lighting, utilities, etc.)
• The social and historical advantages (i.e., preservation)

Table 2.1 – Specific advantages for renovation and reuse of buildings (Highfield, 1987)

2.1.3 Planning for Renovation or Reuse

A renovation/reuse project will often be subject to a number of diverse constraints. Some constraints may be of a physical and dimensional nature, while others are imposed by design considerations, building codes, insurance requirements, or by regulations that become effective as soon as an existing building is tampered with (Lion, 1982). For successful project planning, all relevant factors should be evaluated for their feasibility. This evaluation may include a diligent site inspection and survey, examination of site conditions, testing of load capacities and material qualities, assessment of deterioration and damages, assessment of the building systems' characteristics and capabilities, and environmental and energy considerations. Consideration should also be given to the design and construction aspects of the renovation, since the cost and duration of these activities may have a major impact on the feasibility of the project.

2.2 Building Performance

As described in section 2.1, a facility may become obsolete because the building fails to fulfill certain needs of the user, and/or the user's needs change in a way that cannot be fulfilled by the building. This condition frequently results in buildings that are functionally obsolete in some way.

2.2.1 Obsolescence

2.2.1.1 What is Obsolescence?

Obsolescence can be defined as "the condition of being antiquated, old-fashioned, or out-of-date (Lemer, 1996)." Obsolescence is often the result of a *change in the requirements or expectations* regarding the use of a particular object or idea (Lemer, 1996). It is important to distinguish "obsolescence" from "deterioration," the physical reduction in strength or quality of a material over time. A given building's asbestos insulation, for example, may be in excellent physical condition, showing no signs of deterioration, but current standards prohibiting the use of asbestos in buildings make the insulation obsolete.

Two models illustrate this distinction. Samuel Y. Harris (1996) developed the first model to describe the deterioration process over time, which he illustrates as a decay of the system's "energy" (shown in Figure 2.1). Deterioration of a building system receiving normal maintenance follows an S-curve, deteriorating gradually at first, then accelerating until reaching total functional failure of a system, after which time the rate of deterioration decreases. Harris calls the point of inflection in the normal decay curve the "half-life" of a system, which varies for each building system (e.g., ~100 years for a structure, ~20 years for roof, ~15 years for HVAC machinery). Most buildings' "energy" levels would place them in the incipient or accelerating deterioration regions, while decelerating deterioration is normally relevant only to vacant buildings and historic ruins. *Repair*, as shown in the figure, adds an amount of "energy" to the system, while *mitigation* of deterioration decreases the rate of deterioration for a certain amount of time. After either intervention method, the deterioration process begins again immediately. A series of repair and/or mitigation interventions can keep the systems from reaching their point of failure, theoretically forestalling deterioration indefinitely.

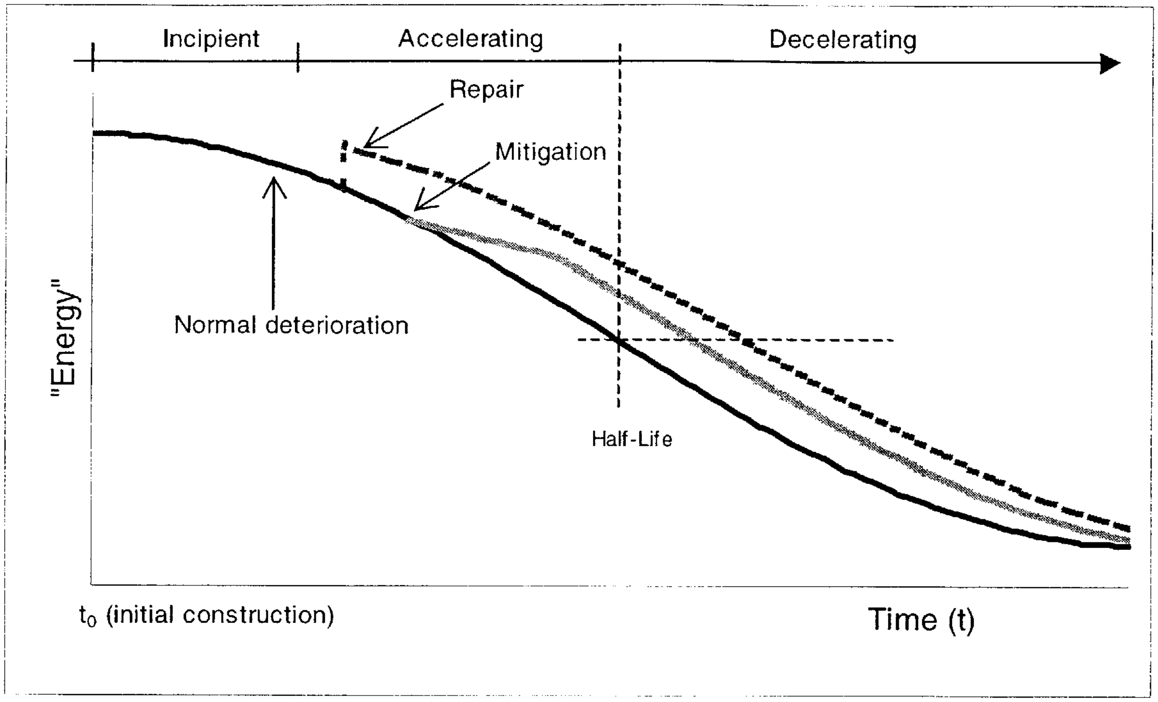


Figure 2.1 –Energy Model of Deterioration (Harris, 1996). Intervention to forestall normal deterioration is shown, through repair and mitigation. The half-life of a building system represents the point of total functional failure.

The second model was developed by Andrew C. Lemer (1996) to illustrate the effects of the expectations of performance on a building system's design service life (see Figure 2.2). Soon after initial construction is completed (after "the bugs" are worked out), the performance of the system meets the expectations of optimum performance. After a time, deterioration sets in, gradually degrading the building system's performance. Finally, the system reaches its design service life, when performance is expected to fail to meet the minimum acceptable performance level (i.e., it becomes "obsolete"). If performance standards increase over time, the system is perceived to reach its design service life early, since it cannot perform better than the minimum acceptable level. Similarly, if new standards are applied (e.g., new federal/state/local regulations), the service life of a system may be shortened. Unlike deterioration, repair and mitigation intervention may be of no use in extending the design service life of a system, since the minimum acceptable performance level of a system will someday exceed the initial optimum performance level.

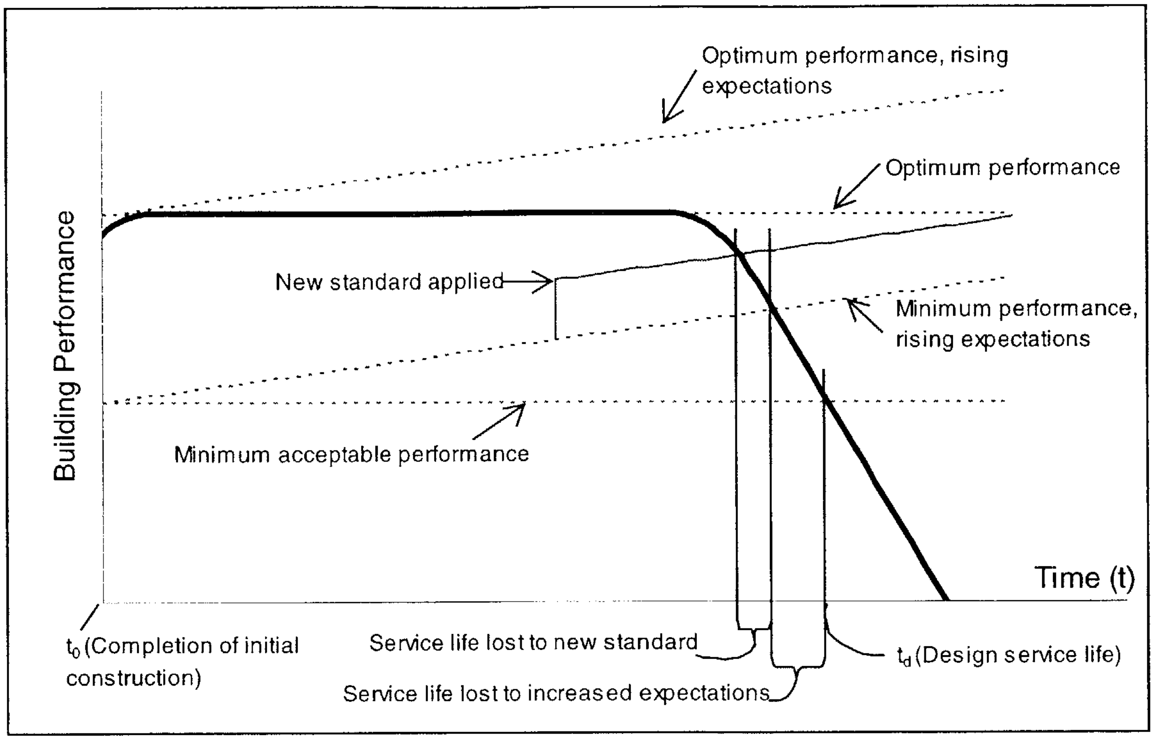


Figure 2.2 – Model of Failure through Obsolescence (Lemer, 1996). As the standards of minimum and optimum performance change, service life is lost. Service life is also lost to the application of a new standard (e.g. Government regulation)

Iselin and Lemer (1993) explain that the "costs of obsolete facilities are incurred when the effort is made to update the facility or when the user and owner lose operating efficiency owing to facility performance. It is these costs—imposed directly on the owners and managers of facilities, indirectly on users, or both—that are the primary incentive to avoid obsolescence."

2.2.1.2 How does Obsolescence Occur?

Factors that cause obsolescence in infrastructure can be grouped into four broad categories: (1) technological changes that influence the scope or level of service that the infrastructure is to provide; (2) regulatory changes that impose new requirements on infrastructure; (3) economic or social changes in markets within a region that alter the demands placed on infrastructure; and (4) changes in values or behavior of infrastructure users that similarly alter demands (Lemer, 1996). All of these factors cause the level of a system's minimum acceptable performance to increase with time.

In highly competitive, high-technology industries, the gap between optimum performance and minimum acceptable performance is very narrow, and the rate at which the expectations of system performance are increasing may be very high. For facilities with a long construction duration (e.g., greater than 3 years), a system may be designed years before construction is complete, at which time the minimum performance already exceeds the optimal performance level at the time of design, a phenomenon called "obsolete before complete" (Iselin and Lemer, 1993).

2.2.1.3 How can Obsolescence be Forestalled?

Iselin and Lemer (1993) recommend several strategies (shown in Table 2.2) for facilities managers to attempt to forestall and/or avoid obsolescence in their facilities. The first two strategies focus on planning and reviewing facilities with respect to future foreseen changes. The next three recommendations concentrate on designing to accommodate change. The next two emphasize good management practice in construction, and the final strategy encourages managers to deal with existing obsolescence.

• On a continuing basis, review new developments for trends that may foster obsolescence
• Conduct facilities programming to address explicitly the possibilities of future functional change
• Assure that design guidelines and criteria that are based on the latest available information and provide for future change, giving particular attention to facility types that are more susceptible to obsolescence
• Make flexibility an explicit design goal, and make appropriate use of design details that enhance flexibility or adaptability
• Assure that facilities fit occupants' needs and gather information for more effective accommodation to occupants' needs in future facilities
• Use alternative procurement methods to reduce the time between initial specification and in-service utilization of facilities or components that may be "obsolete before complete"
• Assure quality in construction and maintenance
• When obsolescence does occur, acknowledge it and retrofit and reuse facilities to minimize costs of obsolescence

Table 2.2 – List of strategies for forestalling obsolescence (Iselin and Lemer, 1993)

As stated in section 2.2.1.1, repair and mitigation intervention may be of no use in preventing obsolescence, since the minimum acceptable performance level of a system will eventually exceed the initial optimum performance level. Some systems, however, may accept *upgrades* that increase the performance level of the system, allowing the system to keep pace with increasing performance standards. The ease with which these upgrades are accepted can have a major impact on the effective life of a system.

2.3 Building Flexibility

In London in the early 1990's, there was unmet demand for affordable housing and an enormous oversupply of office space. A study was performed "to assess the feasibility of reducing the stock of unoccupied office buildings through conversion to meet demands for new housing." As a part of this study, technical constraints to conversions of this type were identified and examined (Gann and Barlow, 1996). Following from these identified constraints, the researchers recommended factors that should be considered in evaluating and designing buildings that could be favorable for conversion. Included in their findings was the statement: "change of use can...be understood in terms on the degree to which different elements of the built environment can be adapted." The researchers also recommended the creation of a "'capacity to change' index...to promote increased *flexibility* in design."

2.3.1 What is "Flexibility?"

For the purpose of this research, "flexibility" will describe the capacity of a building or building system to accommodate the change types mentioned above. A highly flexible system is capable of accommodating many types of changes, and/or certain types of changes for a long time, while an inflexible system is not. This capacity includes the ability of a system to accommodate changes resulting from interactions with other building systems. A highly flexible system should be effective in meeting changing performance standards, and should therefore be useful in forestalling the onset of obsolescence within a building system.

"Flexibility" is a widely used (and frequently inconsistently used) term referring to the adaptability of a building's features to the needs of its users. The term "flexible" is often used to describe buildings that are blocky, boring, and—when put to the test—actually quite inflexible because of missing spare parts, incompatible systems, or just plain, bad planning. Often times, an inexpensive structure that can be amortized in just a few years—in essence, a disposable building—will be described as a "flexible building" (Sennewald, 1987). Another definition of a flexible facility is "one that, in an ideal world, the operations could change overnight" (Patterson, 1998).

2.3.2 Why is Flexibility Important?

Owners and occupants are both recipients of the benefits resulting from flexible building systems. Two of the most frequently cited goals of owner-occupants in modernization projects are (1) "We want to reduce building operating costs," and (2) "We need to handle future corporate growth" (Fischer, 1999). Flexible systems, in different designs, are capable of achieving both of these goals, especially when frequent rearrangements and changes contribute substantially to operating costs. Reducing building operating costs can reap tremendous rewards by increasing a building's investment value (Fischer, 1999). As the renovation trend continues, building owners become more interested in retaining the value and in the flexible utilization of existing buildings (Bernet, et. al, 1995). Since buildings are assets that can be bought and sold, a building's future owner and occupant may have changing intended uses for the building. The capacity of a building to accommodate these future occupants' needs could have a major impact on the building's resale value.

Any facility can become obsolete, but those types of facilities that serve more rapidly changing activities (such as hospitals, laboratories, and schools) are particularly susceptible to the problems of obsolescence (Iselin and Lemer, 1993). Many offices now have annual churn rates (the ratio of the square footage area which is rearranged in a year, to the net leaseable floor area) in excess of 100%, and may have major changes in layout in the course of a year (Watkins-Miller, 1996; Kent, 1997; *Business Week,* 1998). Since the specific details of these changes are typically unknown at the time of initial construction, a high capacity to accommodate these changes (i.e., high level of flexibility) becomes important for minimizing the cost of rearrangement, as well as the downtime resulting from interruption of activities while rearrangements are implemented. Architect Francis Duffy states, "We need to rethink not only how buildings are put together, but how they are used over time" (Duffy, 1992).

Buildings often undergo renovations that create changes in usage class. Christopher Maury (1999) examined fifteen buildings that underwent renovations from one building class to another, including buildings that underwent multiple changes in usage class. The types of usage classes encountered are illustrated in Figure 2.3. While this list is not representative of all types of usage class changes that occur, it shows that a variety of these changes are possible, and frequently undertaken.

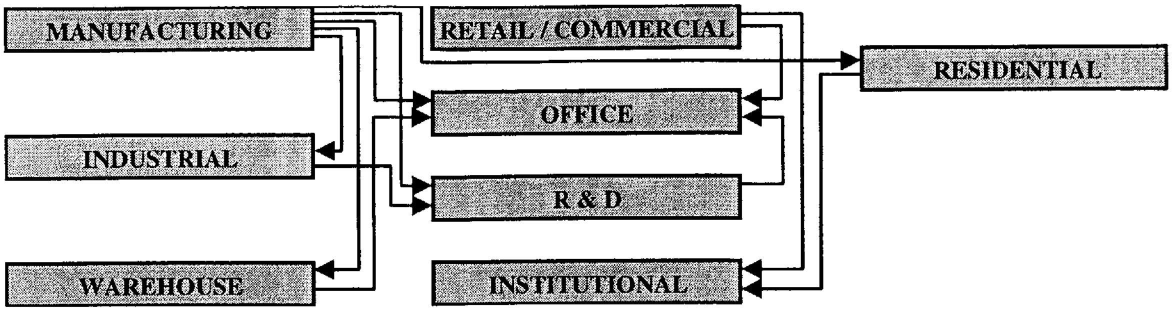


Figure 2.3 – Diagram of building usage class changes encountered (Maury, 1999)

2.4 Building Evaluation

Buildings are assets whose costs and benefits vary over time, as illustrated in Figure 2.4. Initially, buildings generate no revenues, but require initial investments to be made for design and construction. After construction is completed, the facility can generate revenues in the form of rent (or, in the case of an owner-occupant, savings of rent normally paid to a landlord), during which time, some costs are periodically incurred for renovations, upgrades, etc. Finally, the facility is deteriorated to the point that renovation is not cost effective, and the building is decommissioned at some cost. After decommissioning, the facility might be renovated for adaptive reuse, in which case the facility could once again generate revenues (characterized by the dashed line in Figure 2.4).

2.4.1 Life Cycle Cost Evaluation

The Life Cycle Cost method (LCC) is a simple, accepted method of evaluating the investment in a building and balancing it against the discounted profit stream over the same period of time. It is also used to compare design alternatives that compete primarily on the basis of costs (Ruegg and Marshal, 1990). This method involves summing the total investments made to design, construct, operate, and often resell a building, while discounting the investments by a constant (or variable) rate over time. Four variables must be known for each investment: (1) the magnitude of the cost, C_t; (2) the time when the cost is incurred, t; (3) the discount rate used for evaluation, d; (4) the total time period of assessment, N. The LCC is evaluated using Equation 2.1.

$$LCC = \sum_{t=0}^{N} \frac{C_t}{(1+d)^t}$$

Equation 2.1

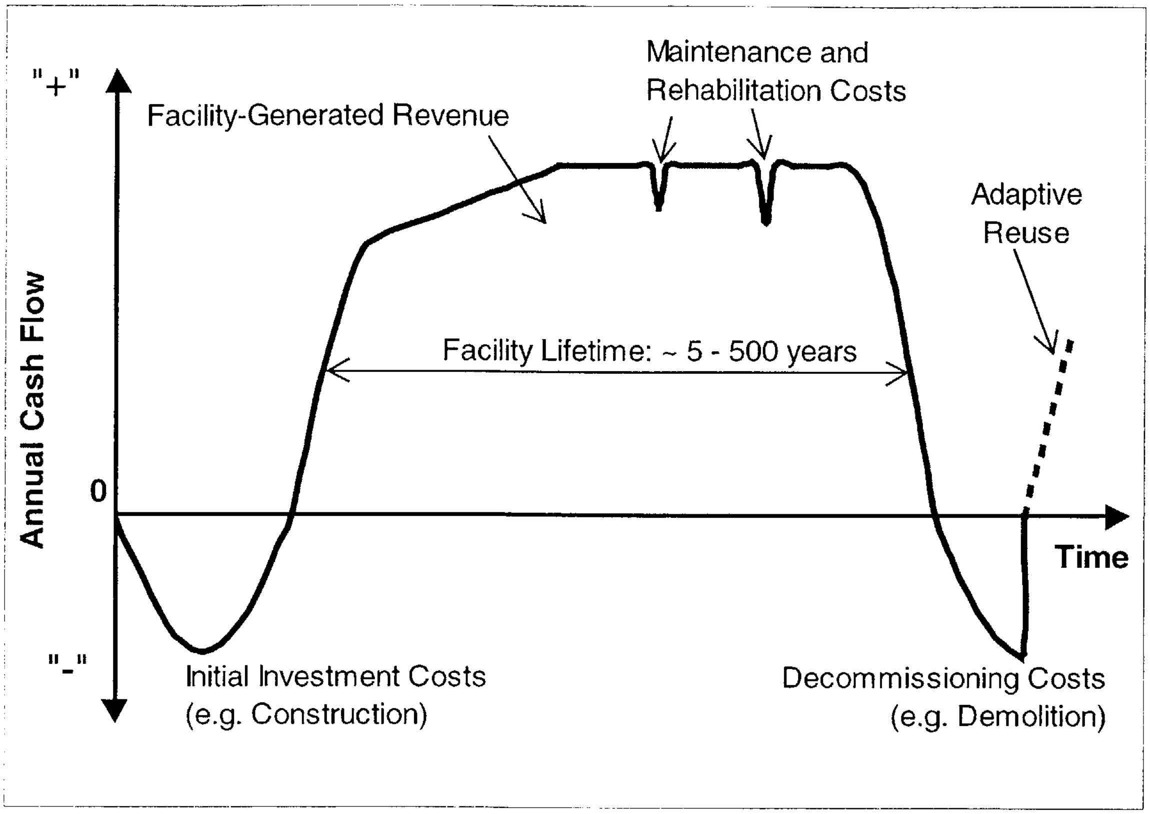


Figure 2.4 – Model of the Product Life Cycle and Facility Generated Costs and Revenues (Slaughter, 1997)

2.4.1.1 Problems with the LCC Method

For LCC to be effective, reviews of design alternatives taking into consideration life cycle costing should be done at the earliest possible stages of facility design so that changes may be made, if warranted, with minimum adverse effect to the project's implementation as a whole (Dell'Isola and Kirk, 1983). However, when the scope, cost, or timing of future changes is vague or indeterminable at the time of initial design, the necessary variables in Equation 2.1 cannot be reliably determined.

Commonly, the aspects of change are evaluated separately from the initial building investment. The LCC for various initial design alternatives for a building are evaluated, and an acceptable alternative is selected. Later, when a change is considered, the cost and benefits of the change are balanced against the option of not implementing the change (i.e., the "do nothing alternative"), and the change is either selected for use, or abandoned.

When a change is evaluated for a flexible system, the costs of the change resulting from construction and/or downtime are presumably less than the cost of changes to an inflexible system. While the cost of adding a flexible system *at the time of the change* (or of replacing an existing system with one that is more flexible) may be prohibitively expensive, the installation or replacement costs might have been quite affordable at the time of initial construction. It is therefore reasonable to assume that if the potential changes are understood well enough during the initial planning stage, the potential future savings might offset additional costs in the LCC evaluation. In essence, the flexibility in the building system pays for itself.

The most obvious problem with the LCC evaluation method is that it is only capable of comparing quantifiable dollar amounts. Evaluating the utility derived from other factors, such as aesthetics, historic value, and comfort, is highly subjective and most often omitted from LCC evaluation (Ruegg and Marshal, 1990). Costs and benefits such as productivity changes and downtime resulting from a selected alternative may be quantifiable to some degree, but are often neglected in computation of the LCC.

2.4.2 Building Systems

Past research has examined buildings as a hierarchy of systems, as shown in Figure 2.5, especially for the case of assessing the condition of a building as a function of the level of component deterioration (Uzarski and Burley, 1997). The hierarchy creates manageable units that can be individually examined and analyzed, while accounting for the fact that given building components may be quite different, due to the building's age, complexity, use, and material categories (Uzarski and Burley, 1997).

Other researchers have defined buildings as assemblies of major systems. For example, a building could be comprised of a **structure** (including foundations and superstructure), **enclosure** (exterior walls, openings, and roof), **interior finish** (partitions, openings, wall and floor coverings), and **services** (e.g., mechanical, electrical, and conveyances) (Lion, 1982). Other studies examine more or fewer systems, depending on the scope of the research. For example, one group of researchers examining the conversion of office space saw buildings as only structure, enclosure, and services (Gann and Barlow, 1996). In this case, the researchers did not identify the interior finish system to be a factor of critical importance to the technical feasibility of the conversions under consideration (i.e., the finish would be completely removed and replaced during conversion), so that system was disregarded.

It is important to recognize that a building is comprised of many building systems, and that these systems are essentially assemblies of individual components. Each system or component is an entity that is neither completely dependent on, nor completely isolated from the other systems or components in the building. For each research project, it appears that the proper systems to be considered are dependent on the scope of the research.

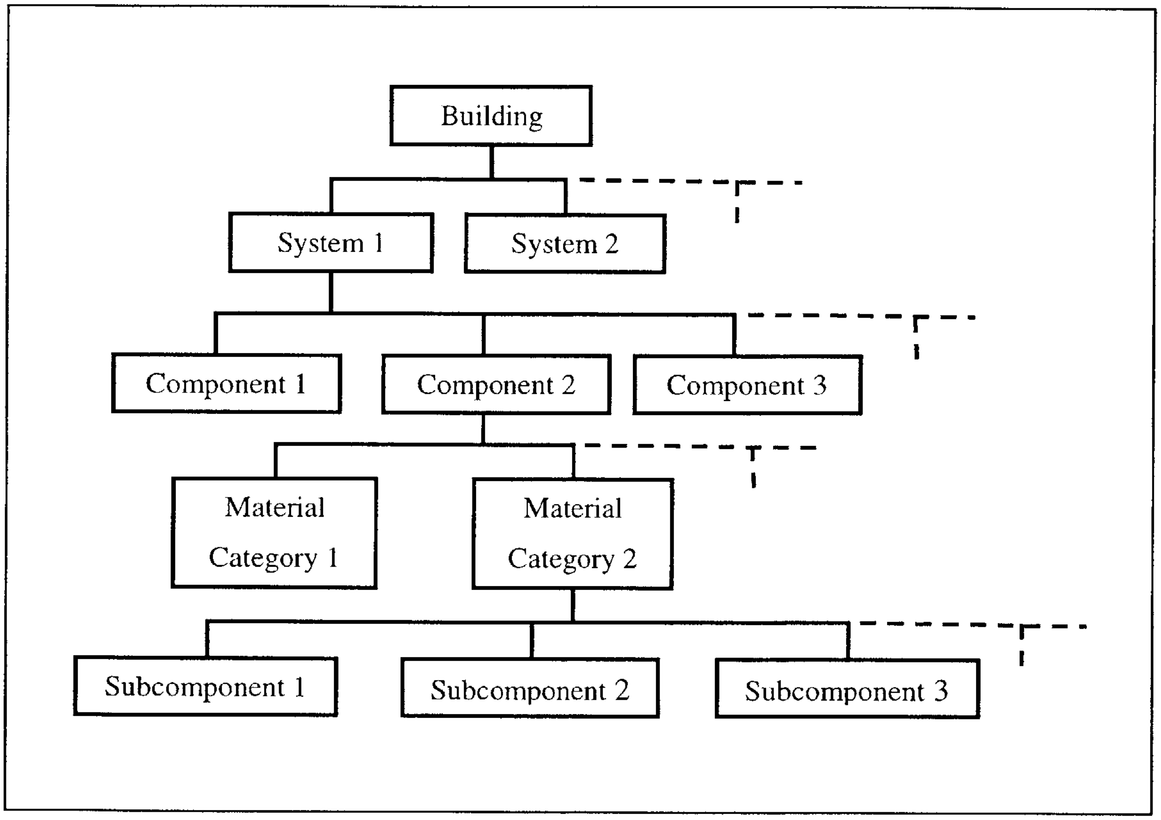


Figure 2.5 – Hierarchy of building systems (Uzarski and Burley, 1997)

2.5 Designing to Accommodate Change

There are different theories about the general ways to improve the flexibility of buildings and building systems, and different means of achieving them. These can be classified as *design approaches* or *design strategies*.

A design approach is a goal or a set of goals to enable a facility to accommodate future changes. It is generally applicable to many buildings and building systems, regardless of location, construction type, size, etc. For example, a design approach may be to improve the "slippage" between the systems (i.e., reduce the impacts of interactions).

Three general design approaches emerge from the current literature. The first design approach involves the prefabrication of major system components (Gann and Barlow, 1996; Glen, 1994). The second design approach calls for designs exceeding the expected load capacity of a system, as it is currently constructed (Glen, 1994; Brand, 1994; Iselin and Lemer, 1993). Finally, the third approach involves the physical separation of systems, allowing a certain amount of "slippage" for each system to accommodate changes independently (Glen, 1994; Brand, 1994).

A design strategy is an explicit action taken to improve the flexibility of a building or a building system, in a way that fulfills a goal set forth in the selected design approach. The strategy will be applied to a specific system (or set of systems) and may only be valid for systems or buildings with certain characteristics, such as size of floor plate area, type of construction, usage class, or geographic location. For example, a design strategy might be to use modular interior wall systems that may be de-mounted and erected elsewhere in a building. This strategy follows the design approach example listed above (i.e., it limits the interaction between the structure and interior finish systems).

Design strategies and design approaches are discussed in greater detail in Chapter 3.

2.5.1 Flexible Designs are Dependent on the Building Type

Commonly, a building is designed to accommodate only the needs of the first tenant or the existing usage class, rather than with consideration for future occupants or uses (Gann and Barlow, 1996). It can be expected that certain user types will influence the level and type of flexibility that can be found in a given building. Laboratory users, for example, frequently require more flexibility in the service and finish systems than, say, office tenants, to accommodate rapid changes in lab equipment and the reorganization of space into larger or smaller units (Nadel, 1996). In particular, the *accessibility* of the services in laboratories is of prime importance to these users (Sennewald, 1987). Hospitals and other healthcare facilities are expected to need and provide flexibility in their interior finish systems, allowing them to subdivide space into manageable units (Meara, 1993).

2.5.2 Flexible Designs are Dependent on the Building Systems

Some authors believe that the flexibility of one system may be highly influenced by the flexibility or characteristics of another. Gann and Barlow (1996) state that "the degree to which the fit-out [room services and interior finish] of a building can be changed will depend on decisions made about the structure and core services provided." It is therefore expected that some design strategies will require changes to be made to one system, in order to provide flexibility in another.

Some authors felt that flexibility in a certain system is generally more important than flexibility in others. "The longevity of buildings is often determined by how well they can absorb new **services** technology" (Brand, 1994). The accessibility of wiring is thought to be of primary importance for many building occupants (Brand, 1994; Iselin and Lemer, 1993). Structure and configuration are believed to influence flexibility only to a limited degree (Glen, 1994). Conveyances are likely to be adequate for most types of conversions (Gann and Barlow, 1996). These factors, combined with the belief that service provision is the most difficult and costly aspect of provision (Gann and Barlow, 1996) imply that many design strategies encountered will focus on improving the flexibility of the services, while few will focus on providing flexibility in the structure and conveyances.

2.6 Summary

Much of the past research into the flexibility of buildings to accommodate change has focused on the renovation of buildings that are historically significant or very old and unoccupied. Research has examined the characteristics of a building and their influence on the capacity of a building to accommodate change, including the technical feasibility of conversion from one particular usage class to another. System vendors or manufacturers often perform evaluations of design strategies that examine the impact on the cost of initial construction only, and the impacts on the flexibility of the system as an isolated entity.

This research examines strategies that are applicable to new construction or renovation of existing old, recently constructed, or new buildings. Characteristics of design strategies and their influence on the capacity of a building to accommodate change will be examined, rather than focusing solely on building characteristics. Conversion between multiple potential usage classes will be examined, as will the impact of the design strategy on future operations & maintenance costs, and the cost of implementing changes. Most importantly, this research examines the secondary and tertiary effects on each system's flexibility resulting from interactions among and between systems.

3 Framework

3.1 Design Strategies vs. Design Approaches

3.1.1 Design Approaches

Before the analysis framework can be explained, the units of analysis—design strategies and design approaches—must be discussed. A design approach is a goal or a set of goals to enable a facility to accommodate future changes. Design approaches are much more general than design strategies, and do not describe the specific action by which flexibility will be increased. Design approaches often are not generalized across systems or subsystems. For example, an approach may be to improve the "slippage" between the systems (i.e., reduce the impacts of interactions). This approach is applicable to any subsystems within the building, and specifies neither the particular action taken to reduce interactions, nor the extent to which the interactions should be reduced.

3.1.2 Design Strategies

As stated in section 2.5, a design strategy is an explicit action taken to improve the flexibility of a building or a building system. An example of a design strategy that increases the capacity of a building system to accommodate change is the use of modular wiring systems; their modularity allows the electrical subsystem to be easily rearranged and rewired through simplified connections.

Since the design strategy is the primary unit of analysis, the independence from individual buildings and applicability of the design strategies to a range of projects are very important. Design strategies can be applicable to many buildings; while a given strategy may be more effective in achieving flexibility when a building possesses certain characteristics or attributes, the strategy must not be specific to an individual building. The limitations of the strategy (i.e., required building characteristics and attributes) are addressed in the analysis framework.

Many design strategies fulfill the goals set forth by one or more design approaches. While the unit of analysis for this research is the design strategy, the effectiveness and characteristics of a design approach can be inferred by evaluating the design strategies that are associated with a particular design approach.

3.2 Theoretical Framework

A four-step process illustrates the evaluation method, as shown in Figure 3.1. The first step of the analysis framework is to group the design strategies into clusters by their characteristics. For the purposes of this research, the design strategies were grouped by their general means of achieving flexibility, and these clusters include the three design approaches identified in current literature. Analysis of each cluster provides information about the effectiveness, feasibility, and value of strategies that meet these general objectives. Other characteristics may be used for clustering, yielding information about strategies using those characteristics.

The three subsequent steps in the framework reflect the expected decision-making process for selection of a design strategy on a particular project. First, a building user's needs are examined and classified, and design alternatives are considered that would fulfill the needs of the user. The flexibility provided by each design strategy is matched to the user's needs, and strategies that do not meet the needs of the user are eliminated. Second, the limitations of the most favorable alternatives are examined to determine whether or not the strategy is technically feasible, and those that are not feasible are eliminated. A given strategy might be eliminated if, for example, it is applicable only to low-rise buildings and the user's building is a high-rise (e.g., modular panel cladding systems may not be durable enough to withstand wind loads above a certain height). Finally, the costs and benefits of favorable alternatives are examined to determine the value of the flexibility gained from each strategy. The costs and benefits, which can be quantitative and qualitative information, provide the data that allows a user to rank the applicable design strategies by cost effectiveness, and select the proper design strategy (or set of strategies) for their building project.

3.2.1 Step 1: Identification of Clusters

The first step in the framework groups the design strategies into "clusters" that display common characteristics. Clusters can be identified among design strategies by design approaches, means to achieve flexibility, common objectives, construction type, or any of the measures identified in Table 3.7. By examining groups of design strategies with one or more similar characteristics, general trends in the data can be identified, and conclusions can be drawn about strategies that possess the general characteristics. The results of this analysis provide evaluation data about the design approaches and clusters which, for the purposes of this research, were grouped by the general means by which they achieve flexibility in a building system (Table 3.1). Detailed descriptions of each cluster are given in Chapter 5.

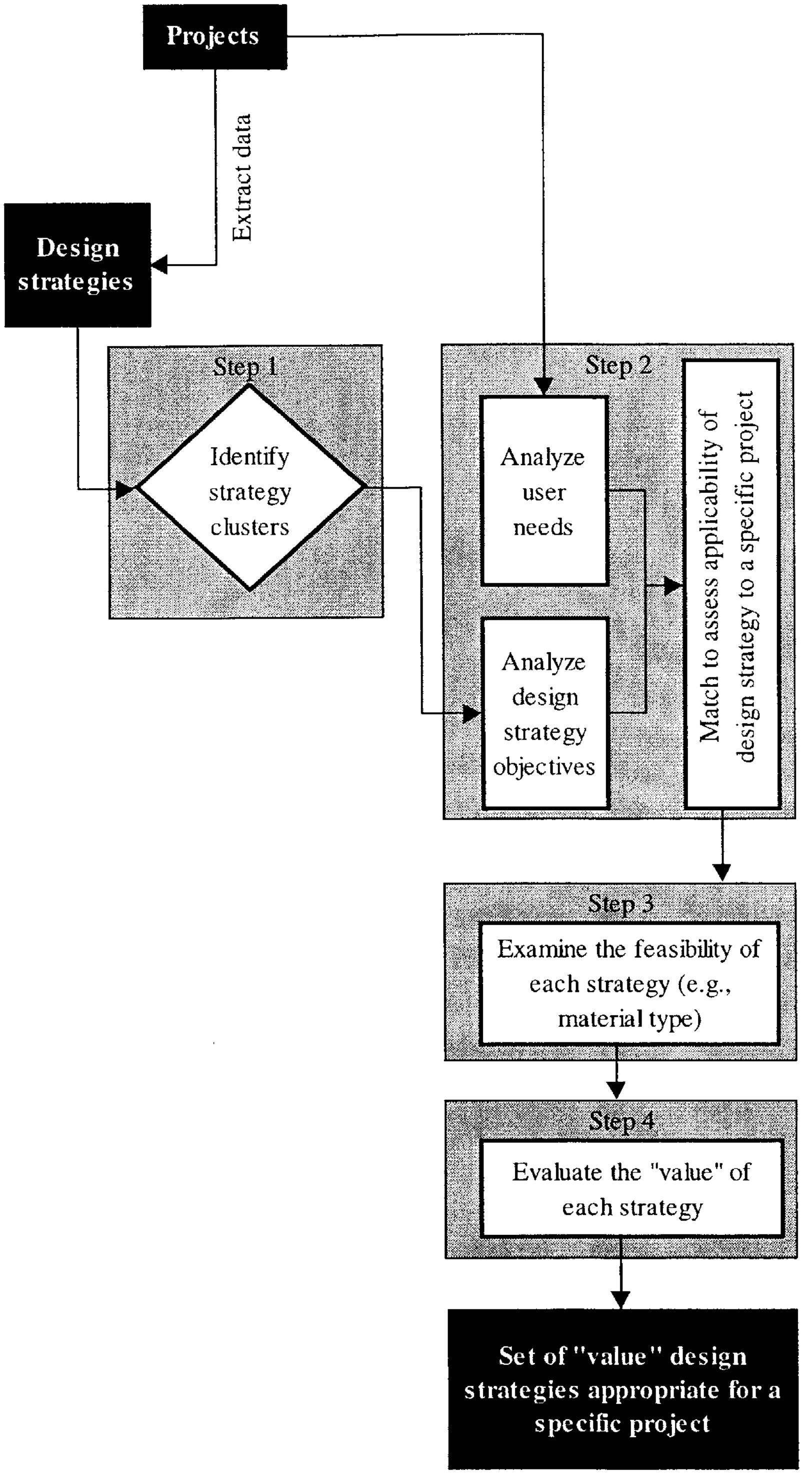


Figure 3.1 – Model of the Five-Step Data-Analysis Framework.

Design Strategy Clusters	
Design Approaches	1. Prefabricate major system components 2. Design over capacity 3. Separate major building systems
Means of Achieving Flexibility	1. Reduce intersystem interactions 2. Reduce intrasystem interactions 3. Use interchangeable system components 4. Increase predictability 5. Improve physical access 6. Dedicate volume for system zoning 7. Phase system installation 8. Simplify demolition 9. Enhance system proximity 10. Improve flow through system layout

Table 3.1 – Clusters of design strategies analyzed

3.2.2 Step 2: Assess the Effectiveness of Strategies

Measuring something as abstract as the effectiveness of a design strategy was one of the most difficult parts of the evaluation process, since effectiveness cannot be quantified beyond vague measures of relative success (i.e., highly successful, moderately successful, etc.). Since these measures could be judged differently depending on the perspective of a given individual, a more specific measurement tool was devised. This measurement required a system to categorize the expected and accommodated changes, and a way to compare the flexibility achieved to the needs of building owners and occupants.

3.2.2.1 Building Systems and Subsystems

An important element in this research is the definition and analysis of a building as an assembly of systems and subsystems, which interact with one another. It is important to recognize not only the ways that systems and subsystems act independently from others, but the ways that these systems and subsystems affect one another. Systems do not necessarily interact in a hierarchical fashion, nor do they interact in a single fashion, and these interactions must be carefully examined in a thorough evaluation of a building.

A model developed by Stewart Brand (1994) shows six “layers” of building systems (Figure 3.2), each of which changes at a different rate. “Site” is the geographical setting, external to the building. “Structure” represents the foundation and load-bearing components, which are perilous and expensive to change, and may have a life of 30-300 years. “Skin” is the exterior surface of the building, which changes about every 20 years to keep up with fashion and technology. “Services” are the working parts of the building (wiring, HVAC, plumbing, etc.), systems that tend to wear out or become obsolete every 7-15 years. "Space plan" refers to the interior layout, including walls, floors, and doors. In high-end offices, the space plan may change completely about every three years, while in homes, changes are much less frequent (e.g., 30 years). Finally, "stuff" represents the interior furniture, appliances, telephones, etc., items that may move daily or monthly (Duffy, 1989; Brand, 1994).

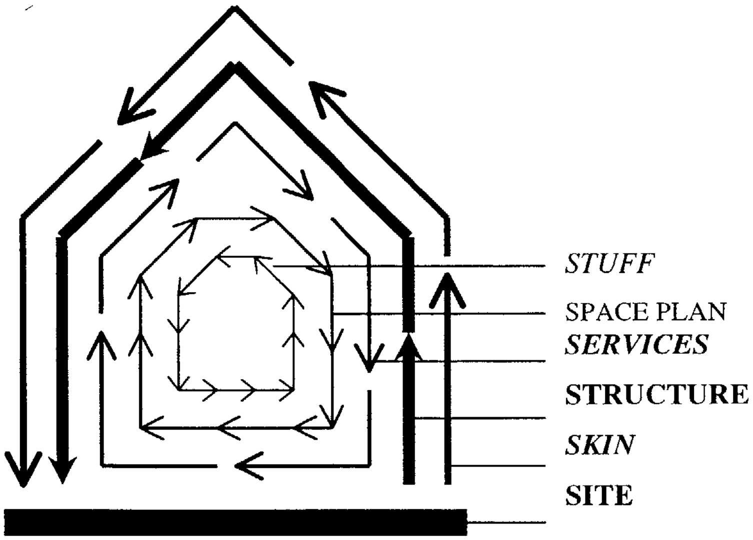


Figure 3.2 – Model of the Shearing Layers of Change: "Because of different rates of change of its components, a building is always tearing itself apart." (Brand, 1994)

According to Brand, the six layers are designed, for the most part, independently of one another. Changes in the building are dominated by the slowly changing components, with the rapidly changing components simply following along: site dominates the structure, which dominates the skin, and so on for the services, space plan, and stuff, respectively. For example, a change in how a room is heated depends on how it relates to the heating and cooling services, which depend on the energy efficiency of the skin, which depends on the constraints of the structure. Still, influence does percolate in the other direction. The slower change processes of a building gradually integrate trends of rapid change within them: for example, if an office keeps replacing its electronic "stuff" often enough, management will insist that the space plan acquire a raised floor to make the constant rewiring easier—the slower-changing finish layer is made to accommodate changes in the faster-changing service layer (Brand, 1994).

3.2.2.2 Building Systems in Evaluation

For the purposes of this research, built facilities are examined as a set of functional systems, which may or may not be physically distinct: for example, a window is a component within both the exterior enclosure system and the interior finish system. The systems of a building are divided into four general classes: (1) structure; (2) enclosure; (3) services; and (4) interior finish. (Slaughter, 1997) Each class of systems can be further divided into subsystems (Table 3.2). Within each system are certain standard alternatives that can be distinguished by their material and functional characteristics; for example, for the superstructure, standard alternatives exist in structural steel, cast-in-place concrete, precast concrete, masonry, and timber, with specific systems that operate as rigid, semi-rigid, or braced frames (Slaughter, 1997).

Systems	Structural	Enclosure	Services	Interior Finish
Sub-systems	Foundation & Substructure Superstructure	Walls Roof Apertures	Heating Ventilation Air conditioning Lighting Electrical Telecommunications Computer communications Security systems Plumbing Fire protection Conveyances Specialty systems	Floors Walls Apertures Ceilings

Table 3.2 – List of general building systems and subsystems

3.2.2.3 Interactions Within and Among Systems

The systems within a building can interact through various mechanisms, and the nature of those interactions and the systems themselves influences the flexibility of the building to respond to different types of changes. System interactions can be grouped into three general categories: physical interaction, functional interaction, and spatial interaction (Slaughter, 1997).

Physical interactions among building systems can be through a connection, intersection, or adjacency. A roof element, for instance, can be mechanically connected to the structure, interleaved through the structural elements, or simply rest upon the structure. Systems can *interact functionally* in ways that enhance, complement, or degrade current functions. For example, an exterior wall can provide additional shear capacity to a structural framing system; operable windows can complement a ventilation system; operable windows can degrade performance of heating or cooling systems. *Spatial interactions* occur when systems operate independently within a certain spatial region (a room, for example). For instance, lighting within a room spatially interacts with interior surface finishes differently for work at a desk with paper, and work at a table with a computer. While these systems may not physically or functionally interact, their spatial interaction may be most important for the owner's perception of the adequacy of the building (Slaughter, 1997).

It is important to recognize the impacts resulting from interactions between systems when evaluating the construction, operations and maintenance, and decommissioning of a facility, since the impacts may create large secondary-effects in construction complexity, as well as labor and cost estimates. Each system in a building can be considered an independent entity in evaluation, as long as the impacts resulting from interactions of that system with other subsystems can be clearly identified and analyzed. One specific impact is the risk of *progressive failure*, a phenomenon that occurs when the failure of a given subsystem directly results in the failure of another. For example, using site-fixed panel partitions provides simple behind-the-wall access to wiring systems. If the wiring system has characteristics that enhance its flexibility (e.g., modular wiring systems), but the site-fixed panel partitions fail to provide adequate access, the wiring system also fails to achieve its flexibility.

3.2.2.4 Change Types

A building system can be expected to experience three general types of changes (Table 3.3): changes in function, changes in capacity, and changes in flow, each of which can be further partitioned into more specific changes. Changes in function occur to achieve specific objectives, and include (1) upgrading existing functions, (2) incorporating new functions to achieve new objectives, and (3) modifying to accommodate changes in usage class. Changes in capacity relate to a facility's ability to meet certain performance requirements, and include (1) changes in loads or conditions, and (2) increase and/or decrease in volume. Changes in flow refer to the movements within and around a building, and can relate to (1) environmental flows, such as heating, cooling, and ventilation, and (2) the flow of people of objects around or through a building space (Slaughter, 1997). While these change types do not describe in detail the specific changes that a facility undergoes, the more specific changes can be classified into one of the general types.

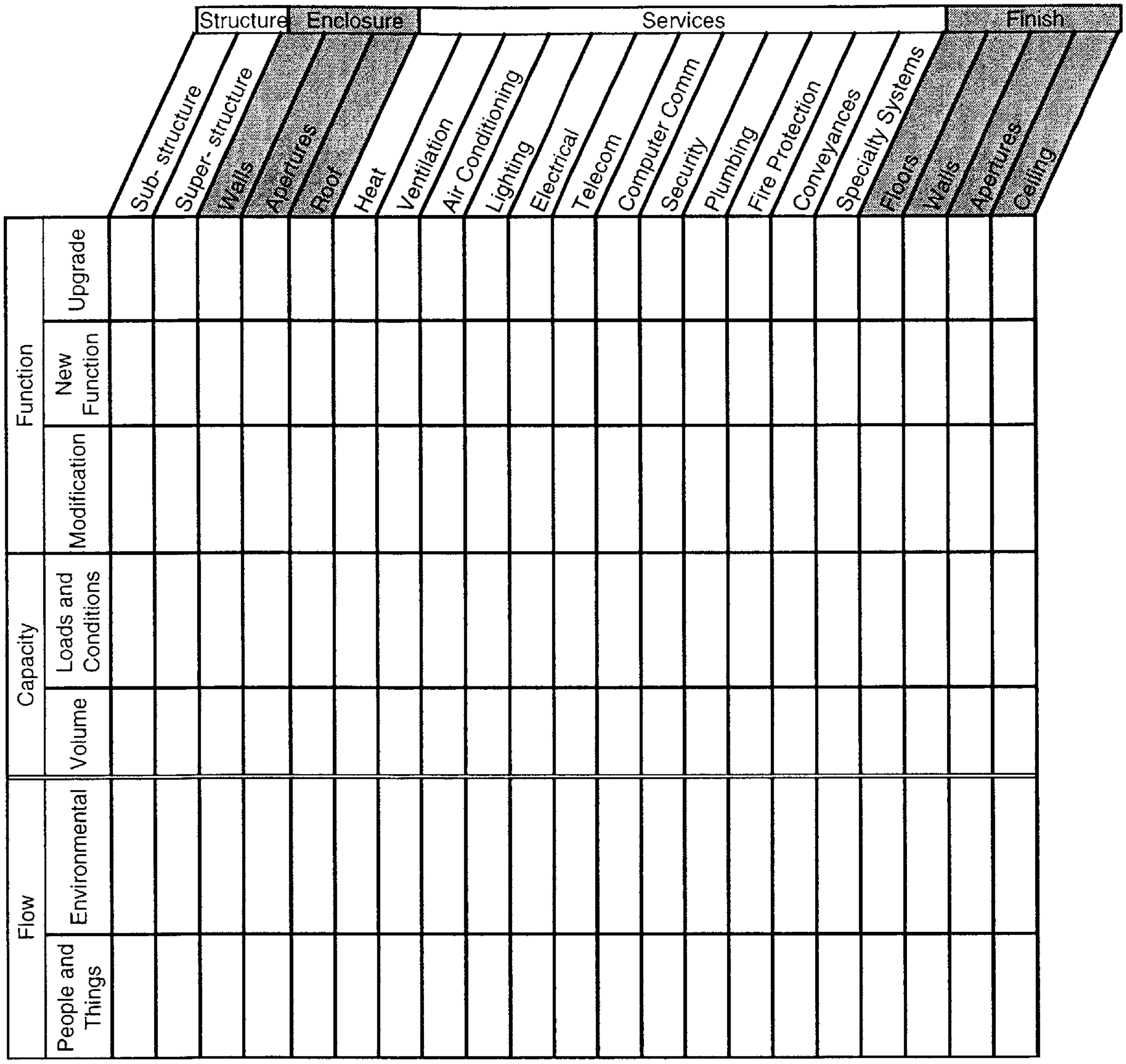
CHANGES IN FUNCTION	**Relates to the set of activities of components that work together to achieve a specific objective**
UPGRADE	The upgrade of existing facilities to meet the requirements of the building's current usage class. (e.g., Improve and/or repair the HVAC system)
NEW FUNCTIONS	The incorporation of new functions within existing facilities to meet the requirements of the building's current usage class. (e.g., Add air conditioning to the current ventilation system)
MODIFICATION	The modification of an existing facility to meet the requirements of and accommodate a new usage class. (e.g., Add bathrooms, etc., to change an office building into apartments)
CHANGES IN CAPACITY	**Relates to the ability of a facility to meet certain performance requirements**
LOADS/CONDITIONS	The ability of a facility to meet certain performance criteria in loads and conditions for a particular usage class. (e.g., Increase the number of outlet terminals in the electrical subsystem)
VOLUME	The incorporation of changes in overall building volume, or in system volume within a facility, to meet the requirements of the usage class. (e.g., Phased development, or the addition of floors)
CHANGES IN FLOW	**Relates to the interactions between a facility and the surrounding environment and its usage population**
ENVIRONMENT	The incorporation of changes in the surrounding or internal environment within a building or facility. (e.g., Enhance the ventilation system through operable windows)
PEOPLE/THINGS	The incorporation of changes in the passage, movement, or organization of people and objects within or around a building's space. (e.g., Create a new stairway, or rearrange partitions)

Table 3.3 – Definitions of Building and System Change Types (Maury, 1999)

3.2.2.5 User Needs

User needs can be defined in a matrix form as the intersections of building subsystems and the change types expected for a specific usage class with respect to a specific building. As shown in Figure 3.3, the horizontal axis of this matrix delineates the building systems and subsystems, and the vertical axis lists the seven general change types.

Each need for flexibility that a building owner or occupant has can be classified as the intersection of the appropriate subsystem and change type. For example, a building occupant who expects to need to rearrange office space could classify the necessary change types listed in Table 3.4 using the matrix shown in Figure 3.4.



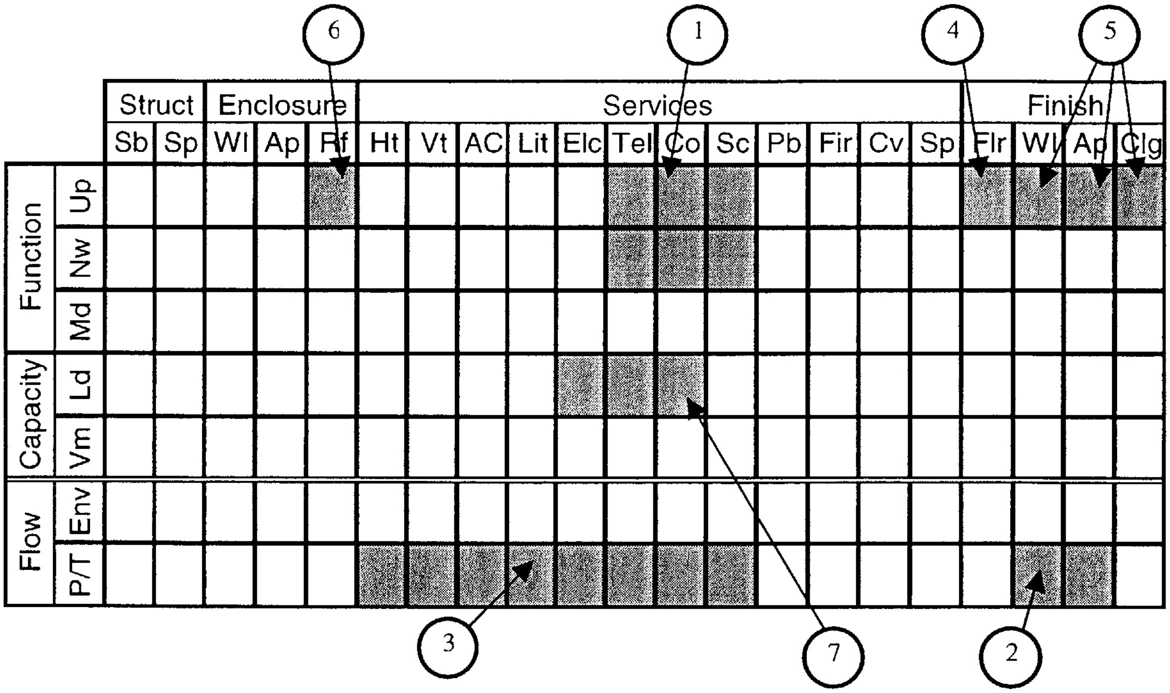
		Structure		Enclosure			Services												Finish			
		Sub- structure	Super- structure	Walls	Apertures	Roof	Heat	Ventilation	Air Conditioning	Lighting	Electrical	Telecom	Computer Comm	Security	Plumbing	Fire Protection	Conveyances	Specialty Systems	Floors	Walls	Apertures	Ceiling
Function	Upgrade																					
	New Function																					
	Modification																					
Capacity	Loads and Conditions																					
	Volume																					
Flow	Environmental																					
	People and Things																					

Figure 3.3 – Matrix showing the intersections of building subsystems and building change types

The needs that a building user has will change over time. Some changes occur frequently, such as multiple times per year (e.g., rearrangement of partition layouts in some buildings), while other changes may not occur until several years after initial construction is completed (e.g., the addition of a new floor on top of the existing structure). The evaluation in this research considers changes that occur at all stages in the life of the building, including initial construction, operations and maintenance, repairs, renovations, decommissioning, and adaptive reuse. Therefore, a third dimension—time—was added to the matrix in Figure 3.3. Three separate matrices were used to

Expected changes to be accommodated
1. Telecommunications and computer communications performance standards are expected to increase drastically as technology advances, requiring upgrades and the incorporation of new functions (e.g., video teleconferencing capability)
2. Office space is expected to be rearranged to accommodate new offices
3. Many services will have to be rearranged to accommodate new layout changes
4. Carpeting will wear out and need to be replaced relatively frequently
5. Interiors will change to keep up with fashion
6. Roof will need to be repaired relatively soon
7. To accommodate new equipment, more outlet terminals will be required for electricity, telephones, and computers.

Table 3.4 – Sample list of changes expected by an office building owner-occupant.



		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

Figure 3.4 – Matrix used to classify the needs of a particular user, with abbreviations of axes labels (shown in Figure 3.3). The shaded boxes indicate the owner-occupant's needs for accommodating change. Numbers correspond to the change items listed in Table 3.4.

classify the needs, according to those that occur in three timeframe categories, as shown in Table 3.5. *Short-term* needs are common, clearly defined, and possess a high probability of being forecasted at the time of initial construction. *Long-term* needs are often large changes (e.g., a change in usage class), and can be more uncertain and difficult to forecast accurately early in the construction process. *Medium-term* needs have characteristics that fall between the short- and long-term needs, and often track to predicted technological advancements (e.g., development of wireless technology for the workplace).

Timeframe category	**Approximate timeframe of expected change**
Short-term	1-5 years
Medium-term	5-15 years
Long-term	15-30 years and beyond

Table 3.5 – Timeframe Categories Used to Classify User Needs

3.2.2.6 Strategy Achievements

Just as a user's need can be classified using the matrix system above, the flexibility achieved by a strategy can be represented in matrix form as the intersections of subsystems and the change type that is accommodated. However, the level of flexibility achieved by a strategy is assumed to be constant with time (i.e., strategies have the capacity to accommodate change at an indefinite time—changes may occur in the short, medium, or long-term).

Because of the interactions between systems, some strategies may require changes to the design and/or construction of a one or more *different* system or subsystems. For example, a building's ventilation system could use the plenum beneath a raised access floor to distribute air, rather than use conventional steel ducts, allowing ventilation patterns to change by simply adding or moving floor panels containing vents. While the strategy provides flexibility to the heating, ventilation, and air conditioning subsystems (within the services system), implementing the design strategy requires changes to the finish system. To capture these factors in the analysis, a third dimension was added to the matrix in Figure 3.3, to separate the systems undergoing a design change from the systems that receive added flexibility (Figure 3.6). This allows *flexibility resulting from interactions* to be highlighted.

3.2.2.7 Matching Matrices

The expanded matrices used to classify user needs and strategy achievements are shown in Figures 3.5 and 3.6, respectively. The shaded intersections in Figure 3.5 indicate the changes that an example user expects to encounter in the future. Changes that an example design strategy is expected to fulfill are indicated by X's in Figure 3.6.

Comparison of the intersections provides an indicator of the effectiveness of the strategy with respect to the user's needs. When the matrices are overlaid and aligned, shaded blocks and X's in the same blocks quickly indicate strategies that may be effective in fulfilling the user's desired needs. This comparison process can be done manually, such as using a light table, or automatically, using statistical analytical techniques. Shaded boxes with no X indicate a goal that is not satisfied by the design. Boxes with X's but no shading indicate flexibility goals that are satisfied but not necessarily desired by the user.

It is important to note that while this quick-comparison method may indicate some strategies that may not be as successful as others in achieving the specific user goals, it should provide an indication of all compared strategies that might fulfill the needs. That is, the process will eliminate those strategies that will definitely not fulfill the users needs, leaving a short list of effective strategies that could be considered for use, once their constraints are identified. Obviously, the more specific the understood need, the more accurate the matching. Since only the general change types are specified, there must be a secondary examination of strategies indicated as being "successful" to characterize the more specific need fulfilled by a design strategy.

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw												▨	▨								
	Md						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T	▨	▨								▨		▨	▨	▨					▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T	▨	▨					▨			▨		▨	▨	▨					▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨							▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T	▨	▨					▨			▨		▨	▨	▨					▨	▨	

Figure 3.5 – Sample user needs matrix – Abbott Laboratories, Las Colinas, Texas

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X													
	Nw						O	O	O													
	Md																					
Capacity	Ld						X	X	X													
	Vm																					
Flow	Env						X	X	X		X	X	X	X						X	X	X
	P/T						X	X	X		X	X	X	X						X	X	X

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X		X	X	X	X					X			
	Nw										X	X	X	X					X	X	X	
	Md										X	X	X	X					X			
Capacity	Ld										X	X	X	X								
	Vm																			X	X	
Flow	Env										X	X	X	X					X	X	X	X
	P/T										X	X	X	X					X	X	X	X

Figure 3.6 – Sample design strategy achievements matrix – Access floor delivery system

3.2.3 Step 3: Identify the Strategy Feasibility

It is important to recognize the feasibility of a strategy's use. In the first step, a building user's general needs might theoretically be fulfilled by a strategy that is inapplicable to the particular building type or construction method. For example, the exterior wall knockout panel strategy requires extra reinforcing steel to be provided in load-bearing concrete walls, in such a way that a panel can be sawed out and removed without requiring structural rehabilitation in the wall. The main technical constraint is the use of load-bearing concrete walls—this strategy does not work in glass curtain wall or conventional masonry structures. A similar strategy might be devised for these specific applications, but the concrete wall strategy being considered would be inapplicable.

Strategy feasibility may also be influenced by interactions between and among building systems. Using modular wiring systems may be considered an effective means to accommodate changes to the electrical and communications systems, but if the wiring is routed through conduits behind conventional drywall partitions, the access to the connections constrains the flexibility. If the modular wiring system is distributed to outlets beneath a raised access floor, the technical characteristics of the floor improve the ease of construction necessary to accommodate the change, enhancing the flexibility of the wiring strategy.

The general technical feasibility constraints can be categorized as shown in Table 3.6. First, a particular *material type* may be required to use the design strategy (e.g., steel structural frame, rather than concrete). Second, a design strategy may require one or more systems to accommodate a certain minimum *load capacity* (e.g., the columns and footings must be strong enough to support additional materials). Third, the *dimensions* of a given space may preclude a design strategy's use (e.g., minimum floor-to-floor height). Finally, a design strategy may require a particular combination of specific *components or systems* be used in a particular building system to allow implementation (e.g., partitions that mount to a hung ceiling grid). Each restriction is identified, as are the systems to which the strategy is applied and the systems where the restrictions exist.

Constraint	Description
Material type	A specific material type is either required or disallowed for a building system
Load capacity	Use of the design strategy requires a certain minimum load capacity within a building system
Dimensions	Use of the design strategy requires certain dimensions within a building system
Component or System	Proper use of the design strategy requires a particular product to be in place

Table 3.6 – Descriptions of the categories of constraints to design strategy feasibility

3.2.4 Step 4: Assess the Value of Flexibility

3.2.4.1 What are the Costs and Benefits of Flexibility?

Benefits of design strategies may come in many forms, including reduced financial costs, shortened construction schedule and/or downtime, as well as less-quantifiable aspects like improved aesthetics, ease of construction, safety, and risk of failure. The irrevocability of the commitment to the system designs may also be an important consideration in the valuation of a strategy, since a system design that is easily or cheaply replaced with another reduces the consequences of system failure. Likewise, the "cost" of flexibility (taken here to mean a loss, sacrifice, or detriment, rather than purely a negative financial value) can take the same forms. These costs and benefits may be realized by different parties in the construction process, and may occur at different times during the life of the building.

The three timeframe categories (i.e., initial design and construction, operations and maintenance, change implementation) describe the different types of construction activities that occur in the life of a building. The design strategy is first implemented either during initial construction or renovation, when steps are taken to accommodate changes in the future. A change (or a series of changes) is implemented at some later time. In the time between initial construction/renovation and the first change (and between subsequent changes), the design strategy may directly effect the operations and maintenance activities that occur. The costs and benefits evaluated represent the significant impacts that the design strategy has on the building, user, and owner during these three timeframes.

In the initial construction phase, six different costs and benefits were chosen for evaluation because they were considered to have the most significant impact on a strategy's success. The most obvious costs are those that are incurred as a direct result of changes in construction activities—namely, changes in material and construction process activities. The duration of construction has obvious impacts on the cost, since long construction periods can result in delays to other construction activities, or increased labor and equipment rental costs. Procurement concerns can have similar impacts, since delays in procuring the proper specialty materials can delay other construction activities, or an entire project, if the activity lies on the critical path of the construction schedule. Safety concerns impact projects by increasing safety management costs, and can result in possible injuries to on-site personnel. The difficulty of the design and the ease of construction can have a significant impact, since complex designs may require hiring designers or constructors with special skills at extra cost.

During the operations and maintenance phase of the project, a design strategy may incur direct financial costs by requiring more expensive or more frequent maintenance. The accessibility of systems for repairs impacts the duration and difficulty of O&M activities. The level of commitment to the design strategy can also have impacts on the building in the future. If an alternative is presented in the future that is more economical or appropriate for the building's tenants than the selected design strategy, or in the event of a system's failure, a building owner may wish release the building from the design strategy. Design changes made in implementing a strategy that can be removed or simply ignored minimize impacts to the building owner in the future.

When a change is implemented, direct costs from construction activities and materials are again incurred. Interruption of space and operations can have adverse effects on building occupants, such as power outages in an office that disrupt day to day activities. Accessibility of building systems for renovation effects the difficulty and duration of change construction activities.

3.2.4.2 How Should Costs and Benefits be Measured or Evaluated?

Table 3.7 lists the costs and benefits evaluated or measured for each design strategy in this analysis, along with each associated measurement. The only clearly quantifiable measure used was an order of magnitude estimate of the cost, as compared to conventional techniques. Since cost estimates performed by contractors may vary widely depending on their core capabilities, geographic location, and current construction market, the estimates were used not to determine the specific cost, but to examine the relative impact on the cost. Financial cost information for a given design strategy's initial construction was estimated and expressed as a percentage increase in the total initial construction cost of a building. To provide a baseline for this data, the construction costs for a building in Cambridge, Massachusetts were obtained from the building's developer. For design strategies that are very complex, the costs cannot be accurately estimated using currently available techniques, but may be in the near future with the development of new construction process simulation software. The costs of these strategies are assumed to fluctuate around zero change, depending on various design details, and may be classified as "variable about zero." Financial costs for the operations and maintenance phase are often not documented by building owners and managers, so accurate estimates are difficult to come by. Instead, costs are judged to likely increase or decrease based on the extent and type of new O&M activities required for systems affected by a design strategy, as compared to systems of conventional designs. The cost of implementing a change using the flexible designs is given compared to the cost of obtaining the same end result of the change using conventional construction techniques. For those designs that create the capacity to accommodate a change normally considered cost prohibitive when using conventional construction techniques, the strategy may be classified "alternative cost prohibitive."

To lend a level of repeatability to the "less quantifiable" measurement, the measures are described in terms of explicit criteria (Table 3.7). For example, procurement concerns are classified as either "yes" or "no" depending on whether or not unconventional materials are required, based on the assumption that specialty materials will be more difficult to procure than conventional materials.

3.3 Summary

The framework presented in this chapter provides a tool for analyzing and evaluating the critical characteristics of design. Using the appropriate data, architects, designers, and owners can use this framework to select the best of many design alternatives for their particular projects. In the following chapters, data is presented that was collected from numerous existing or planned projects, to extract the design strategies used. The framework is then used to analyze these design strategies and examine their value with respect to a single sample project.

	COST OR BENEFIT	MEASUREMENT	DESCRIPTION OF MEASUREMENT
Design/Initial Construction	Design difficulty	simple	design is not overly complex or does not require special skills beyond that of ordinary professional designer
		difficult	design is complex enough to require special skills beyond that of ordinary professional designer
	Ease of construction	easy	construction activities require no extraordinary training
		difficult	construction activities require extraordinary training
	Construction duration	no impact	construction duration is approximately the same as with conventional designs
		shortened	construction duration is expected to be shorter than conventional designs
		lengthened	construction duration is expected to be longer than conventional designs
	Safety concerns	no	design strategy presents no significant safety concerns
		yes	design strategy presents significant safety concerns
	Procurement concerns	no	design strategy requires no unconventional materials
		yes	design strategy requires unconventional materials
	Financial cost	percent change	percent change in cost of building from conventional construction
		variable about zero	complexity of system designs prohibits accurate cost estimation, and system cost varies positively and negatively depending on specific design attributes
Operations and Maintenance	Financial cost	increased	O&M activities are more expensive, difficult, and/or time consuming
		not significant	O&M activities are no more expensive, difficult, and/or time consuming than for conventional designs
		decreased	O&M activities are less expensive, difficult, and/or time consuming
		not applicable	design requires no maintenance
	Accessibility for operations and maintenance	no change	accessibility for repairs is neither better nor worse than in conventional designs
		improved access	accessibility for repairs is much easier than in conventional designs
		worsened access	accessibility for repairs is much more difficult than in conventional designs
		not applicable	there are no O&M costs associated with either the design strategy or the conventional alternative
	Irrevocability of commitment	none	in the event of failure, a new design can be used at minimum cost
		significant	in the event of failure, a new design can be used, but at a major cost
		total	in the event of failure, the design cannot be replaced affordably
Change Implementation	Financial cost	change in cost	change in cost of implementing a change in the design strategy as compared to conventional construction techniques
		variable about zero	complexity of system designs prohibits accurate cost estimation, and system cost varies positively and negatively depending on specific design attributes
		alternative is cost prohibitive	design strategy allows a change not feasible, either technically or economically, when conventional designs are used
	Downtime	no impact	during a change, the interruption of occupied space is the same as for conventional designs
		shortened	the interruption of occupied space is shorter than when conventional designs are
		lengthened	the interruption of occupied space is longer than when conventional designs are
	Accessibility for renovation	no change	accessibility for change construction is neither better nor worse than in conventional designs
		improved access	accessibility for change construction is much easier than in conventional designs
		worsened access	accessibility for change construction is much more difficult than in conventional

Table 3.7 – Descriptions of the Measurements of the Costs and Benefits of Flexibility

4 Methodology

4.1 Data Collection

Data for this study was empirically based, coming from existing projects throughout the world, and was collected in three steps. First, an extensive literature search was conducted to identify projects that appeared in newspapers, journals, books, and/or internet web sites, on a local, national, or international scale. Second, a survey of the largest property owners in the United States was conducted, offering them an opportunity to identify flexible design strategies of their own, or projects where they have used flexible design strategies. Finally, interviews were conducted with engineers, developers, owners, architects, planners, and consultants, to identify flexible design strategies that they had encountered in their experience.

The relevant data collected pertained to the technical/engineering aspects of the design strategy, including cost, time, and safety data, for initial construction, implementation of a change, and for operations and maintenance. A sample sheet for collection of the design strategy's data is shown in Figure 4.1.

Throughout the collection process, occupied structures that incorporate strategies specifically accounting for future needs were considered valid projects. The term "occupied structure" applied to such facilities as offices, residential developments, in-patient medical facilities, retail stores, control centers, educational facilities, R&D (research and development) labs, and fabrication facilities. Other, non-occupied facilities were ruled out (e.g. a waste-sorting facility in the Netherlands that would later be converted into a concert hall is not considered an occupied facility).

4.1.1 Identification of Projects and Design Strategies through Literature Searches

Extensive literature searches were conducted, to find articles identifying appropriate design strategies for accommodating future changes, buildings that were or will be designed using these strategies, or industry players who frequently incorporate design strategies into their building designs. This method led to the identification of most of the strategies in the sample, since many buildings that incorporate these design strategies are consequently considered unique or innovative, and receive extensive coverage in architectural/real estate journals. A large range of literary data sources in many forms was surveyed to provide the largest, most representative view of projects around the world. This search was conducted over many weeks, and was stopped only when newly identified facilities failed to yield new design strategies.

DESIGN STRATEGY NAME: ______________
Facilities using design strategy: ______________
Source of design strategy: ______________

DESIGN STRATEGY APPLIED TO SYSTEM: ______________
ACHIEVES FLEXIBILITY IN SYSTEM: ______________

DESCRIPTION OF STRATEGY: ____

First Construction

- System Design
  - Difficulty: simple / difficult
  - Restrictions (building type, materials, layouts, etc): ______________
  - Design cost concerns: ______________
- System Construction
  - Skills and training procurement: no / yes
  - Ease of construction: easy / difficult
  - Construction duration: shortened / no impact / lengthened
  - Procurement concerns: no / yes
  - Safety concerns: no / yes
  - Process changes: ______________
  - Financial cost: ______________

Operations and Maintenance

- Financial cost: increased / not significant / decreased / not applicable
- Accessibility for in-situ changes: improved access / no change / worsened access / not applicable
- Irrevocability of commitment: none / significant commitment / total commitment

Change Implementation

- Financial cost: ______________
- Downtime: shortened / no impact / lengthened
- Tasks: ______________
- Accessibility for renovation: improved access / no change / worsened access

Figure 4.1 – Data sheet for collection of design strategy data

4.1.2 Identification of Projects and Design Strategies through an Industry Survey

The second method involved contacting 25 of the largest developers and property owners across the United States to discuss whether or not they incorporate design strategies that explicitly account for changing needs of owners and users over time (Table 4.1). These large developers were considered to be representative of the industry in the United States because of their large size and number of projects owned and/or developed. This survey yielded few strategies, and

Company	Location
The Alter Group	Lincolnwood, IL
Breslin Realty Development Corp.	Garden City, NY
Carter and Associates - ONCOR	Atlanta, GA
CIGNA Corp.	Bloomfield, CT
Cornerstone Realty Advisors	Hartford, CT
Duke Associates	Indianapolis, IN
Gosnell Builders	Phoenix, AZ
Hillman Properties	Newport Beach, CA
Hines Interests, Ltd.	Houston, TX
Homart Development Co.	Chicago, IL
Industrial Developments International, Inc.	Atlanta, GA
Koll Real Estate Group, Inc.	Newport Beach, CA
Kornwasser & Friedman Shopping Center Properties	Los Angeles, CA
LaSalle Cos.	Columbus, OH
Lincoln Property Co.	Dallas, TX
MAY Department Stores	St. Louis, MO
Opus Cos.	Minneapolis, MN
Oxbow Realty	Norwood, MA
Pembroke Real Estate	Boston, MA
The Pyramid Cos.	Syracyse, NY
Melvin Simon and Associates, Inc.	Indianapolis, IN
Summit Properties	Charlotte, NC
Trammell Crow Co.	Dallas, TX
The Weston Cos.	Memphis, TN
Zeckendorf Realty, L.P.	New York, NY

Table 4.1 – List of owners and developers contacted and their location within the U.S.

many developers claimed never to have used designs that accommodate future changes (only five of the 25 owners/developers contacted could think of occasions when these design strategies were used).

4.1.3 Identification of Projects and Design Strategies through Interviews

The third data collection method involved conducting interviews with owners, developers, contractors, architects, engineers, and consultants who have experience creating or implementing innovative designs that allow the building to accommodate future changes (Table 4.2). These interviews were highly valuable sources of information, and the interviewees conveyed the importance of many factors not immediately addressed in this research (e.g. zoning restrictions, furniture, future value of system infrastructure to developer, etc.). These interviewees are all involved in buildings that require high performance systems and see a large amount of complementary technology changes. The variety of construction-industry roles represented in the sample provided opinions from many perspectives in the building process.

Interviewee	Company	Position
Mr. Bill Browning	Rocky Mountain Institute	Consultant
Mr. Bryan Clancy	National Development of New England	Developer
Mr. Mark Paris	National Development of New England	Developer
Mr. John Onufrak	Cranshaw Construction	Contractor
Mr. Bob Cunkelman	MIT Physical Plant	Engineer (Owner affiliated)
Mr. Bob Simha	MIT Planning Office	Planner (Owner affiliated)
Mr. Gary Shaw	DTS Shaw and Associates, Inc.	Architect

Table 4.2 – List of interviewees for data collection

Throughout the interviews, it was noticed that the interviewees could not often identify design strategies when simply questioned about their general use; instead, a series of questions was used to elicit the tacit knowledge from these experienced professionals. Eventually, all interviewees were able to identify projects on which they had used some strategies for accommodating future changes.

4.2 Projects Identified

Projects utilizing design strategies were identified across the United States and around the world. A list of the projects identified is shown in Table 4.3. Descriptions of each project are given in Appendix A of this document.

Project	Location
Abbott Laboratories	Las Colinas, Texas
Aberdeen Proving Ground	Aberdeen, MD
270 Albany Street	Cambridge, Massachusetts
Boston University Dorm	Boston, Massachusetts
Building 16, Massachusetts Institute of Technology	Cambridge, MA
Building 314	Indianapolis, Indiana
9/90 Corporate Center	Framingham, Massachusetts
Gap, Inc. Headquarters	San Bruno, California
Igus Factory	Cologne, Germany
K. Wayne Smith Building	Dublin, Ohio
Mashpee Junior/Senior High School	Mashpee, Massachusetts
Metro-Dade Center	Miami, Florida
Mount Auburn Hospital	Cambridge, Massachusetts
Owens Corning World Headquarters	Toledo, Ohio
Revenue Canada Building	Surrey, British Columbia, Canada
San Joaquin General Hospital	San Joaquin County, California
Stata Complex, Massachusetts Institute of Technology	Cambridge, MA
Stop & Shop Grocery Store	Norwood, Massachusetts
Summit Properties Apartments	Charlotte, NC
Toyota Motor Corp. Parts Center	Ontario, California
Unilever Research	Bedfordshire, United Kingdom
US Navy Operational Trainer Facility	San Diego, California

Table 4.3 – List of projects identified that incorporate design strategies to increase the capacity of a system (or systems) to accommodate change

4.2.1 Representativeness of the Sample

Projects were selected over a large geographic area (Table 4.4). While many are located in Massachusetts, many more are located throughout the United States, plus three from foreign countries (Canada, United Kingdom, and Germany). Building size ranged from 50,000-sf to 900,000-sf, and from one to 31 stories in height. The average building size was 265,500-sf, with a median height of 4 stories. The size of the building footprints ranged between 16,000-sf and 760,000-sf.

Geographic Region	Projects
Western US and Canada	5
Midwestern US	4
Northeastern US	9
Southeastern US	2
Europe	2
Total	*22*

Table 4.4 – Geographic representativeness of projects selected

4.3 Design Strategies Identified

Table 4.5 lists the design strategies identified through the data collection process outlined above, along with the names of the project(s) where each strategy was incorporated, where applicable. Some strategies have been generally applied across a set of similar projects, and are therefore not linked to a specific project.

4.4 Base Building Cost Data

As described in Chapter 3, construction costs are expressed as a percentage increase in the total initial cost of constructing a building. To provide baseline data, construction costs were obtained from a local developer of a building in Cambridge, Massachusetts. Construction on the building was completed in 1998, at a total cost of approximately $11.4 million. It is a five-story steel structure on pressure-injected footings with a glass and masonry enclosure system. The total square footage of the building is 124,500-sf, with a 5-bay by 7-bay rectangular floorplate measuring approximately 150-ft by 166-ft. Finish systems are conventional drywall partitions for office space, and services are also conventional.

4.5 Validity, Reliability, and Representativeness of the Data

The list of design strategies is not meant to be inclusive of all options available for use by designers, but rather a diverse list of strategies representing many design options for various building systems. Data and case studies are extracted from actual projects that have been constructed, rather than theoretical buildings, making the data valid and reliable. Costs are reliable only for order of magnitude estimates, and may vary significantly based on the characteristics of individual projects, including building size and shape, geographic location, regional construction labor market, and many other factors.

DESIGN STRATEGY	SOURCE	LOCATION
False slab	*Developer*	--
Exterior wall concrete knockout panels	*Developer*	--
Interstitial mezzanine floor rack system	*Developer*	--
Z-layout configuration	*Developer*	--
Structural "ladder" assembly system	*Developer*	--
Centralized configuration	*Developer*	--
Single/multi-channel surface raceways	Unilever Research *Vendor*	Bedfordshire, United Kingdom --
Overhead cable trays	*Vendor*	--
Structural column overcapacity	Mount Auburn Hospital *Developer*	Cambridge, Massachusetts --
Oversized vertical distribution shafts	*Developer*	--
Two-end core layout	Abbott Laboratories	Las Colinas, Texas
Raised flooring	Abbott Laboratories K. Wayne Smith Building US Navy Operational Trainer Facility	Las Colinas, Texas Dublin, Ohio San Diego, California
Demountable mid-height partitions	Abbott Laboratories Building 314	Las Colinas, Texas Indianapolis, Indiana
Demountable full-height partition walls	Abbott Laboratories	Las Colinas, Texas
Monoblock partition systems	*Vendor*	--
Site-fixed panel partition systems	*Vendor*	--
Utility risers at columns	Abbott Laboratories	Las Colinas, Texas
Room size standardization	Building 314	Indianapolis, Indiana
Column-free zones in structure	Igus Factory	Cologne, Germany
Office pod system	Igus Factory	Cologne, Germany
Modular panel cladding system	Igus Factory	Cologne, Germany
Accessible modular wiring	K. Wayne Smith Building	Dublin, Ohio
Poke-through floors	Metro-Dade Center	Miami, Florida
Exposed ceilings with overhead distributi	Building 314 270 Albany Street Building 16, Massachusetts Institute of Technology	Indianapolis, Indiana Cambridge, Massachusetts Cambridge, MA
Extra fiberoptic lines	Building 16, Massachusetts Institute of Technology	Cambridge, MA
Street layout	Mashpee Junior/Senior High School Building 16, Massachusetts Institute of Technology Aberdeen Proving Ground	Mashpee, Massachusetts Cambridge, MA Aberdeen, MD
High density of electrical outlets	Building 16, Massachusetts Institute of Technology	Cambridge, MA
Small-area VAV units	Stata Complex, Massachusetts Institute of Technology Abbott Laboratories	Cambridge, MA Las Colinas, Texas
Access floor delivery system	Stata Complex, Massachusetts Institute of Technology Owens Corning World Headquarters	Cambridge, MA Toledo, Ohio
Task lighting system	Abbott Laboratories Owens Corning World Headquarters	Las Colinas, Texas Toledo, Ohio
Access floors housing mechanical ducts	Revenue Canada Building Gap, Inc. Headquarters	Surrey, British Columbia, Canada San Bruno, California
Enhanced performance cabling systems	San Joaquin General Hospital	San Joaquin County, California
Interstitial space beneath structural slab	Stop & Shop Grocery Store	Norwood, Massachusetts
Overhead drainage system	Stop & Shop Grocery Store	Norwood, Massachusetts
Extra vacant conduit	Boston University Dorm *Developer*	Boston, Massachusetts --
Extra-fast acting sprinklers	Toyota Motor Corp. Parts Center	Ontario, California
High density of vertical shafts	270 Albany Street	Cambridge, Massachusetts

Table 4.5 – List of design strategies identified that increase the capacity of a system (or systems) to accommodate change

5 Results

As explained in the Framework and Methodology chapters, this research involved the analysis of 37 design strategies extracted from 22 projects. Trends in the data resulting from the analysis are presented in this chapter. First, the user needs for different facility types are examined, revealing the changes expected at a given facility type over the life of a building. Second, the design strategies are evaluated, taking into account impacts over the building life, during construction, operations, and change implementation phases. Groups of strategies with common means of achieving flexibility are examined as well. Finally, design strategies are matched to the needs of users in common building types, including three case study buildings, for which additional or different strategies than those selected by the owner are recommended.

5.1 Classifying User Needs

As discussed, accommodating changes in user needs depends on many factors, which include the building's usage class, local environmental factors, and the building's age, dimensions, and materials. Before any design strategies can be selected for accommodating change, the expected changes must be clearly identified.

The most important part of classifying the needs for flexibility that owners face was being able to do it in a way that is not only consistent, but also replicable. The matrix described in Chapter 3 provides a means to consistently identify each user's needs. The change categories were found to be sufficient to categorize all the expected changes encountered, and the subsystems used adequately described the elements that make up a building. If the needs are not categorized properly, or if new needs are identified, the strategies that have already been characterized will have to be reexamined to determine their effectiveness at satisfying the new needs.

5.1.1 Expected Changes by Usage Class

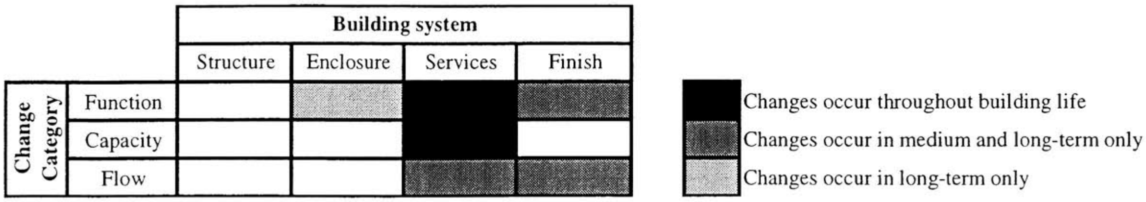
The usage classes of the 22 projects identified are shown in Table 5.1. Owners and occupants of buildings in each usage class expect to experience changes dependent on the use of the space, or the usage class.

Building Usage Class	Projects
Research and Development	270 Albany Street Aberdeen Proving Ground
Office	9/90 Corporate Center Gap, Inc. Headquarters K. Wayne Smith Building Metro-Dade Center Owens Corning Headquarters Revenue Canada Building
Office and R&D mixed-use	Building 314 Unilever Research
Office and Manufacturing mixed-use	Abbott Laboratories Igus Factory
Residential	Boston University Dorm Summit Properties Apartments
Educational	Building 16, MIT Mashpee Jr./Sr. High School Stata Comlpex, MIT U.S. Navy Operational Trainer Facility
In-patient Medical	Mount Auburn Hospital San Joaquin General Hospital
Retail	Stop & Shop Grocery Store
Warehouse	Toyota Motor Corp. Parts Center

Table 5.1 – Usage classes of buildings studied

Typical buildings in each usage class expect certain general changes to occur at different times during the life of the building. These general changes are summarized in Figures 5.1 through 5.9. More detailed changes (i.e., user needs matrices) for these typical facilities are included in Appendix A of this document. Since the short-term changes are expected to continue throughout the life of a building, and medium-term changes are expected to occur again during the long-term, the changes may be grouped into three categories. In each of the following figures, darkest shading indicates changes that occur in the short term and repeat throughout the building life. Medium-gray shading indicates changes that occur in the medium and long term. Light gray shading indicated changes that are only expected to occur in the long term of the building life. Boxes that are split into two or three shaded areas indicate that some subsystems within each system are expected to encounter the general change type at different times.

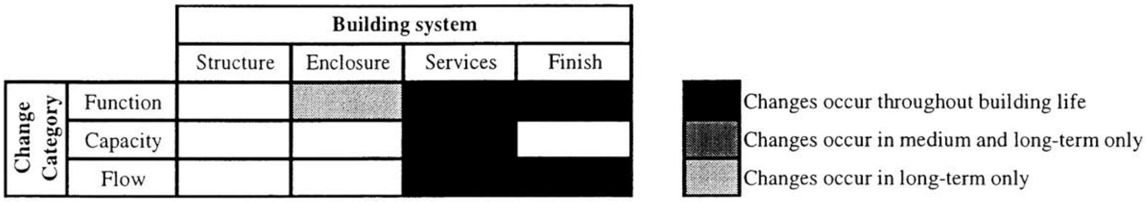
The differences in the expected changes must be recognized when a conversion between building usage classes is planned. Different facilities expect different changes based on their intended use, and the existing facility may have not have been designed to accommodate the types of changes that are expected under the new usage class.



Change Category	Building system: Structure	Enclosure	Services	Finish
Function		░	■	▓
Capacity			■	
Flow			▓	▓

■ Changes occur throughout building life
▓ Changes occur in medium and long-term only
░ Changes occur in long-term only

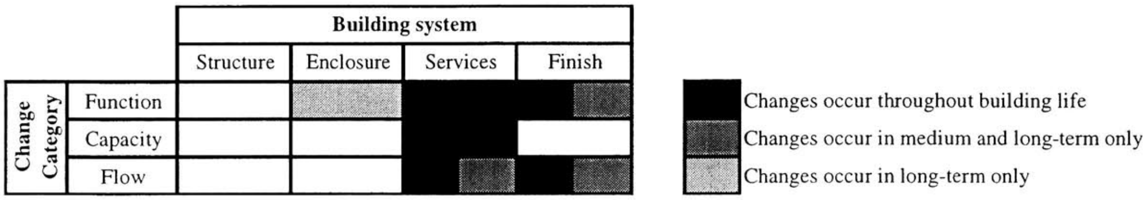
Figure 5.1 – General changes expected by typical research and development laboratories



Change Category	Building system: Structure	Enclosure	Services	Finish
Function		░	■	■
Capacity			■	
Flow			■	■

■ Changes occur throughout building life
▓ Changes occur in medium and long-term only
░ Changes occur in long-term only

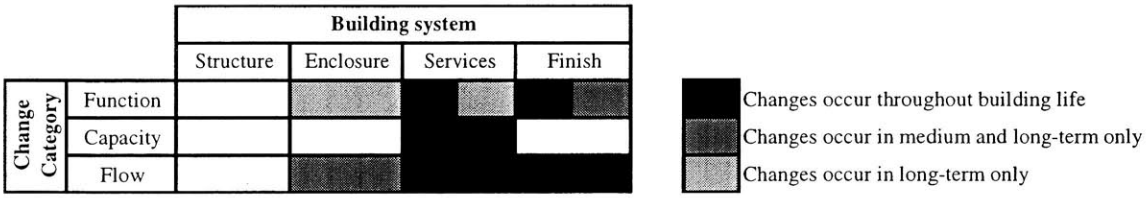
Figure 5.2 – General changes expected by typical office buildings



Change Category	Building system: Structure	Enclosure	Services	Finish
Function		░	■	■▓
Capacity			■	
Flow			■▓	■▓

■ Changes occur throughout building life
▓ Changes occur in medium and long-term only
░ Changes occur in long-term only

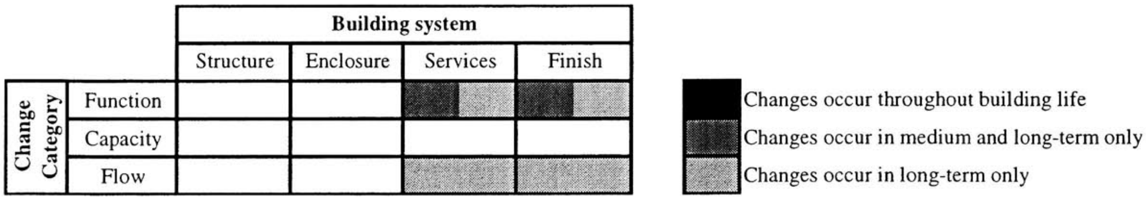
Figure 5.3 – General changes expected by typical office/R&D mixed-use buildings



Change Category	Building system: Structure	Enclosure	Services	Finish
Function		░	■░	■▓
Capacity			■	
Flow		▓	■	■

■ Changes occur throughout building life
▓ Changes occur in medium and long-term only
░ Changes occur in long-term only

Figure 5.4 – General changes expected by typical office/manufacturing mixed-use facilities



Change Category	Building system: Structure	Enclosure	Services	Finish
Function			▓░	▓░
Capacity				
Flow			░	░

■ Changes occur throughout building life
▓ Changes occur in medium and long-term only
░ Changes occur in long-term only

Figure 5.5 – General changes expected by typical residential buildings

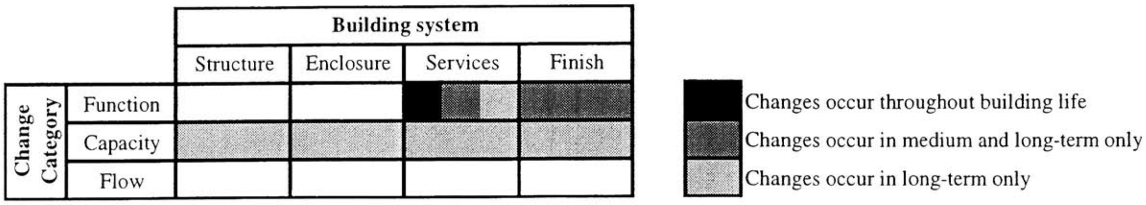


Figure 5.6 – General changes expected by typical educational buildings

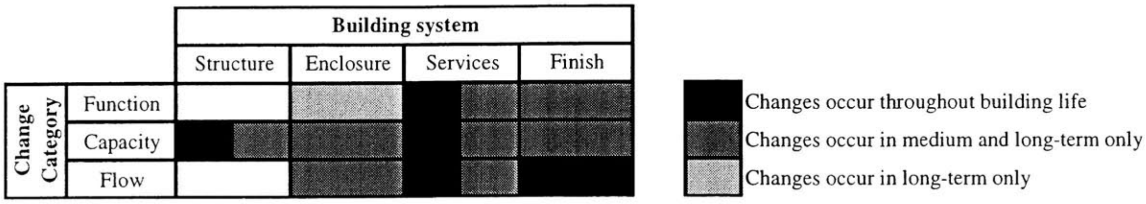


Figure 5.7 – General changes expected by typical in-patient medical facilities

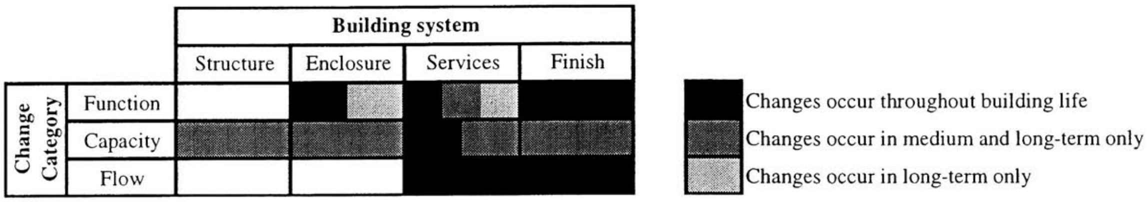


Figure 5.8 – General changes expected by typical retail buildings

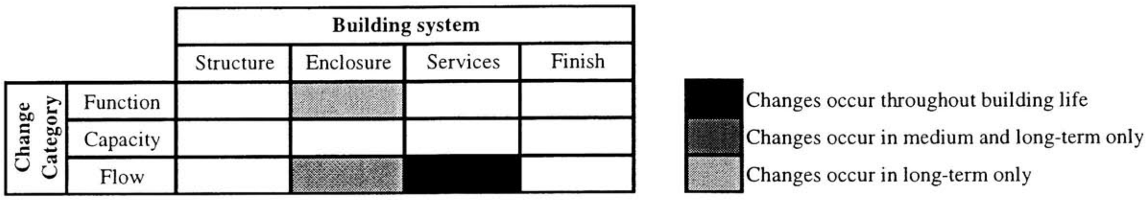


Figure 5.9 – General changes expected by typical warehouse buildings

5.1.1.1 Research and Development Laboratories

The types of changes most often expected at research and development laboratory facilities were frequently changing loads in ventilation, electrical, and plumbing over the life of the facility, since research activities change often, even in the immediate term after initial construction. Rearrangement of spatial allocation is also expected to occur quite frequently in these facilities, requiring reorganization of these services within the space to accommodate new research projects.

Research and development labs must stay constantly on the cutting edge of technological advances, since their business is the advancement of technology itself, so upgrades of electrical, communications, and security services are expected to occur quite regularly throughout a facility's life. For this reason, the main objectives of the strategies used by the laboratory facilities examined are to provide easy access and close proximity to service mains and connections.

Long-term changes in laboratory facilities are fairly certain to occur and to be major in scope, as the facility continues to keep up with the accelerating pace of technological development, but these developments are difficult or even impossible to discern before they actually occur.

5.1.1.2 Offices

Offices experience constant change and "churn" (the rearrangement of facility space), especially with respect to finishes and services, as project teams change and people are relocated throughout the office. To accommodate this change, four of the six offices examined used access floors, allowing them to quickly reroute wiring distribution to any location on the floor.

Keeping pace with the latest technology is of the utmost importance, as is the appearance of the office to current and prospective clients. Therefore, the upgrade of finishes and the incorporation of new service technologies tend to occur quite regularly.

In this sample, the office buildings experienced a high rate of change in these categories within 1-3 years of initial construction, while other less-change-intensive offices would typically experience them in the medium term of 5-8 years.

Changes in the enclosure and structure rarely occur in these building types, and are almost never anticipated during initial construction. The exception is one office that installed higher capacity columns in the structural system to accommodate an additional rooftop chiller unit in a specific location.

Offices are often located in centralized areas within cities, where few other usage classes are encountered or expected. There is some documentation of developers who, in a market with an overabundance of office space and a shortage of housing, have converted large amounts of former offices into residential units. However, office owners examined in this research did not expect this type of change to occur at their facility, so no offices were encountered where existing owner and occupants planned for changes in usage class.

5.1.1.3 Office and Manufacturing

High-tech manufacturing facilities expected to experience constant rearrangement for the flow of products through the facility, which may also require new entrances and exits for people and products through the enclosure. Changes are not expected to occur for the structural system, which is designed to accommodate loads that are quite high (e.g., distributed, unreduced design live load is 300-psf in manufacturing facilities, and only 100-psf in offices). Finish systems are often minimized in these facilities, except for certain sensitive areas such as clean rooms, to which changes are infrequent due to the high risk of contamination. Service systems experience the most changes, since electrical power, communications (for controlling equipment) and plumbing must be distributed to equipment as rearrangement occurs.

The two facilities studied (Igus Factory, Cologne, Germany; Abbott Laboratories, Las Colinas, TX) have manufacturing space and office space that are interchangeable within the facility, either of which may need to grow into the other's space. At Abbott Labs, the generic space can be used for either office or manufacturing, and is divided by full-height demountable partitions that can be moved and re-erected at other locations with virtually no waste. The space at Igus is built to accommodate the manufacturing functions, while offices are constructed in movable "pods" that can be disassembled and rebuilt almost anywhere within the manufacturing space. These two facilities both invested large amounts of money during the initial construction phase to accommodate future changes, each using multiple design strategies (e.g., three strategies at the Igus Factory, and seven at Abbott Laboratories).

5.1.1.4 Residential

Changes expected by residential property owners are relatively rare for both structure and enclosure, but more frequent for the interior finish systems. Changes in large dormitories and multi-family apartments are typically to update the finish systems, and to replace or repair decentralized appliances (e.g., in-apartment air conditioners, refrigerators). No clear strategies were identified that address these changes, however.

The two residential projects examined in this research both used the same design strategy, in which a system of extra vacant conduit is installed during initial construction, originating at a single point in the building and terminating at one location in each unit. This allows new electrical or communications functions to be incorporated without damage to the finish or structural systems, a change type that is increasingly important as information technology moves into the residence. The strategy also provides a level of redundancy, so that replacement wiring can be installed in the event of a system's failure

5.1.1.5 Educational

Educational buildings are often owned and maintained for a very long life, making it almost certain that some major changes will be required over the building's life. Currently, school facilities need to be flexible for wiring changes and realignments, because it is difficult to predict the technologies that will be incorporated throughout a school's long life (Patterson, 1997). This is evident in the increasing pace at which schools throughout the United States are integrating information technology services into classrooms for teaching aids. (Two studies about the use of technology in schools were conducted by the Milken Family Foundation in December 1998 and September 1999 (Solomon, 1998; Solomon, 1999). These studies found that the number of school districts in which most schools are connected to the Internet via a local area network increased from 49% to 60% in just nine months.) All four educational facilities examined have some strategy in place to incorporate new functions in communications, to allow this integration to proceed more easily.

Additions to schools usually include spaces that demand the latest technology and innovative designs, such as computer rooms, music rooms, and gymnasiums (Patterson, 1997). Such spaces are not easily renovated into existing facilities (Patterson, 1997). Therefore, most schools should expect the growth of school facilities (i.e., volumetric capacity expansion).

Higher-education institutions commonly mix office, laboratory, and classroom space within a single building. Rearranging these areas occurs frequently and the space must essentially accommodate a new usage class on a small scale (i.e., integrate new functions using existing system infrastructure). During an interview (Simha, 1999), it was identified that flexible base plans are often developed to aid these changes (e.g., particular column spacing and building perimeter dimensions), which simplify reconfiguration. However, these plans were not identified as having occurred at any of the four facilities examined.

5.1.1.6 In-patient Medical

In-patient medical centers such as hospitals usually stay in an existing location for a long time, and when the current facility is outgrown, expansion is a common solution. New buildings are added adjacent to existing structures and new levels may be added at space-constrained sites. Hospitals often must incorporate new machinery and medical equipment, so the structures must be designed to support large loads, and services must be able to accommodate changing demands in power. Computer communications within medical facilities are becoming a very important part of the day-to-day operations, with personnel continuously accessing and updating patient records at computer terminals throughout the facilities.

The two hospitals examined in this research used design strategies that provided extra load capacity either in the structure (Mount Auburn Hospital) or the electrical and communications systems (San Joaquin General Hospital) to accommodate the changes identified above. Because of the 24-hour operations that go on at these facilities, providing extra capacity allows necessary changes to be made without interruption of services and minimal interruptions of day-to-day operations.

5.1.1.7 Retail

Retail stores experience changes chiefly in service and finish systems, and rarely in the structure and enclosure. The desire to offer and present new products and services to customers faster and better than competitors provides the impetus for change in stores, leading to many changes that may occur quite shortly after initial construction (Rizkallah, 1999). Grocery stores, for example, may try to offer a "one-stop" shopping experience to customers, providing video rental, a pharmacy, a bank, and even gasoline. These markets are intensely competitive, and the ability to subdivide space and incorporate the necessary services for providing these new products and services is of critical importance. In addition to changing finish layouts and electrical power distribution, these stores must be able to rearrange lighting to most effectively display products, and rearrange ventilation diffusers so that air does not blow directly on customers when the space is rearranged.

The single retail project examined included a design strategy that had a relatively high initial cost and drastically reduced the cost and time associated with rearranging the store's refrigeration units. No strategies were identified that improve relocation of finish systems or other services. During an interview, the architect for the chain of stores indicated that flexible systems for building structure, services, and enclosure systems are currently being researched for use in the stores, but he could not comment on the specifics of such designs, for fear of releasing proprietary information to competitors.

Retail space owners (including the owner of the project examined in this research) do not often expect their space to undergo changes in usage class, unless the space is included as part of a mixed-retail facility (e.g., a shopping mall), in which case owners may expect changes of occupants, but not of the general retail atmosphere. Few major changes are needed for such a change to occur, since much retail space is generic in nature (i.e., large, open spaces for storage and display).

5.1.1.8 Warehouse

The changes encountered at warehouses vary by the type of warehouse, its contents, and its geographic location. There is some documentation of the conversion of warehouses to apartments in some urban areas (Spackman, 1999; Wright, 1999). One project examined was a warehouse used to store special parts for making Toyota automobiles. The project had a very specific need for flexibility due to fire codes. In order for plastic parts to be stored in the warehouse, special fast-acting sprinklers had to be in place. While most areas of the warehouse contained parts that did not require use of such sprinkler systems, the owners recognized the importance of being able to change the layout of the stored parts in the future, so the sprinklers were installed throughout the facility to provide this level of flexibility.

5.1.2 Timeframe of Expected Changes

The number of expected changes that owners of the projects wish to accommodate in each term is shown in Appendix C, Table C.1. For this table, a "need" is a shaded intersection of the matrices described in Chapter 3. A description of each project can be found in Appendix A, accompanied by each project's needs, shown in matrix form.

Of the 22 projects examined, eleven had the greatest portion of their changes expected in the short term (1-5 years after initial construction); these projects were offices, offices with manufacturing and R&D, and educational buildings. Five of the six offices anticipated identical, somewhat generic changes in the rearrangement of facilities, and four used raised access floors to achieve the necessary flexibility.

Nine projects expected most of their changes to occur in the medium-term (5-15 years after initial construction); these projects were R&D labs, residential, medical, retail, and warehouse facilities. These facilities have lower churn rates and expect changes to be few in number, but significant in scale.

Only two projects predicted that most changes would occur in the long term (greater than 15 years after initial construction), which is expected, since these distant changes are often difficult to identify (Table 5.2). Both these facilities were educational buildings that were designed to accommodate specific needs which the owners and designers do not anticipate changing over the short or medium terms. The Igus Factory expects a high number of changes in the long term, resulting from a change in the building's usage class, but the very high number of changes expected in the short term outweighs the expected long term changes.

Timeframe of most needs	Number of projects	Percent of total
Short-term	11	50%
Medium-term	9	41%
Long-term	2	9%

Table 5.2 – Timeframe of most change needs for each project

5.1.3 Types of Expected Changes

The most common change types expected were *Upgrade of Functions*, *Incorporation of New Functions*, and *Changes in the Flow of People and Things*, which were each expected in 21 of the 22 projects (Figure 5.10). *Changes in Load Capacity and Conditions* were also frequently expected (18 of 22 projects). Less frequently expected changes were those in the *Changes in Volume Capacity*, *Changes in Environmental Flow*, and *Modification of Functions for a New Usage Class* categories (Figure 5.10).

Of the nine projects that expected *Changes in Volume Capacity,* two were residential projects that expected growth only in the electrical and communications systems. The remaining seven projects expected growth of the entire facility, with the addition of buildings or floors. Two of those seven projects (Igus Factory and US Navy Operational Trainer Facility) were constructed in phases, such that growth of the facility was clearly understood when the first phases were being constructed. Both of these facilities adopted the use of modular panel cladding systems to maximize the amount of reusable material during these changes.

Changes in Environmental Flow were expected in five of the 22 projects. Two projects were the office and manufacturing facilities (Igus Factory, Abbott Labs), which wanted to be able to segregate heating, cooling, and ventilation between the manufacturing and office areas. Two projects were the medical facilities (Mount Auburn Hospital, San Joaquin General Hospital), which may need to change air flows to reduce the risks of contamination or communication of airborne contagion. The fifth facility was a new educational facility (MIT Stata Complex) that plans to have operable windows and an innovative heating control system that automatically closes heat supply vents when windows are opened, to conserve energy.

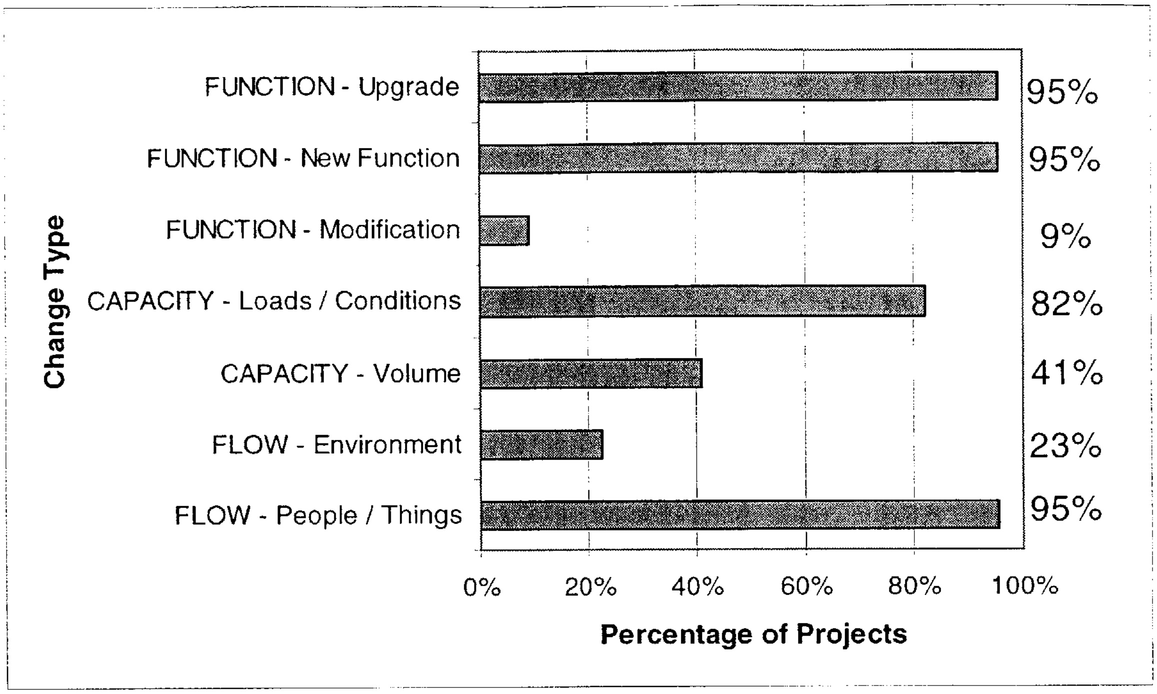


Figure 5.10 – Percentage of projects where users need each change type to be accommodated

All 22 projects examined expected to accommodate changes for the current user within the same usage class. Only two projects (Igus Factory, Abbott Labs) expected to accommodate a new usage class (both are shown in the right-hand column of Table 5.3), and at both projects, the working space is interchangeable between office and manufacturing uses. The Igus Factory also expects to accommodate a *new user* in a different usage class, and the owners specified that the facility be designed to allow resale of the factory space as a supermarket at some later date. The 270 Albany Street project was designed to accommodate research and development for a collaborative team of researchers from two companies for the first few months of operation, after which one of the companies was to take over the entire facility. Changes were needed when this transition took place, and were accommodated during initial construction, but the usage class remained the same.

		Usage Class	
		Same	New
User	Current	(All projects)	Abbott Labs Igus Factory
	New	270 Albany Street Igus Factory	Igus Factory

Table 5.3 – Number of projects where users expect changes in users and/or usage classes to be accommodated

5.2 Evaluating Design Strategies

It is important to note that the sample of design strategies examined is not an inclusive list of all possible strategies available to building designers and owners in the industry. Rather, it is a sample large enough to indicate common characteristics among design strategies, through general trends in a count and frequency analysis. Detailed descriptions of each design strategy are given in Appendix B, followed by each strategy's achievements in matrix form.

5.2.1 Strategies and Change Types

The change types accommodated by the 37 design strategies are shown in Figure 5.11. Two of the most common change types expected by users in the sample (*Changes in the Flow of People and Things* and *Incorporation of New Functions*) were each accommodated by over 80% of the strategies. In contrast, the change type *Upgrade of Functions*, which is also expected by a very large portion of the sample of projects, is accommodated by only 57% of the strategies. *Changes in Capacity* and *Changes in Environmental Flow* were accommodated by approximately 70% of the strategies. The *Modification of Functions for a New Usage Class* was the change type least frequently accommodated by the design strategies (and also the least frequently expected change type). However, nearly half of the design strategies do, in some way, accommodate modifications of function for changes in usage class, which is a significant portion of the sample, indicating that buildings that incorporate specific strategies for accommodating change may be easier to modify for a change in usage class, regardless of whether or not it was intended.

The mismatch in the proportion of change types accommodated and those that are needed (Figure 5.10) is not an indication of needs that are going unfulfilled. Rather, it shows that many strategies have benefits that are unintended, underutilized, or not needed. Users may identify a specific change type that needs to be accommodated, and the selected design strategy may offer more flexibility than users need or even realize exists. A false slab, for example, may be used to accommodate changes in layout (i.e., flow of people and things) that affect the utilities.

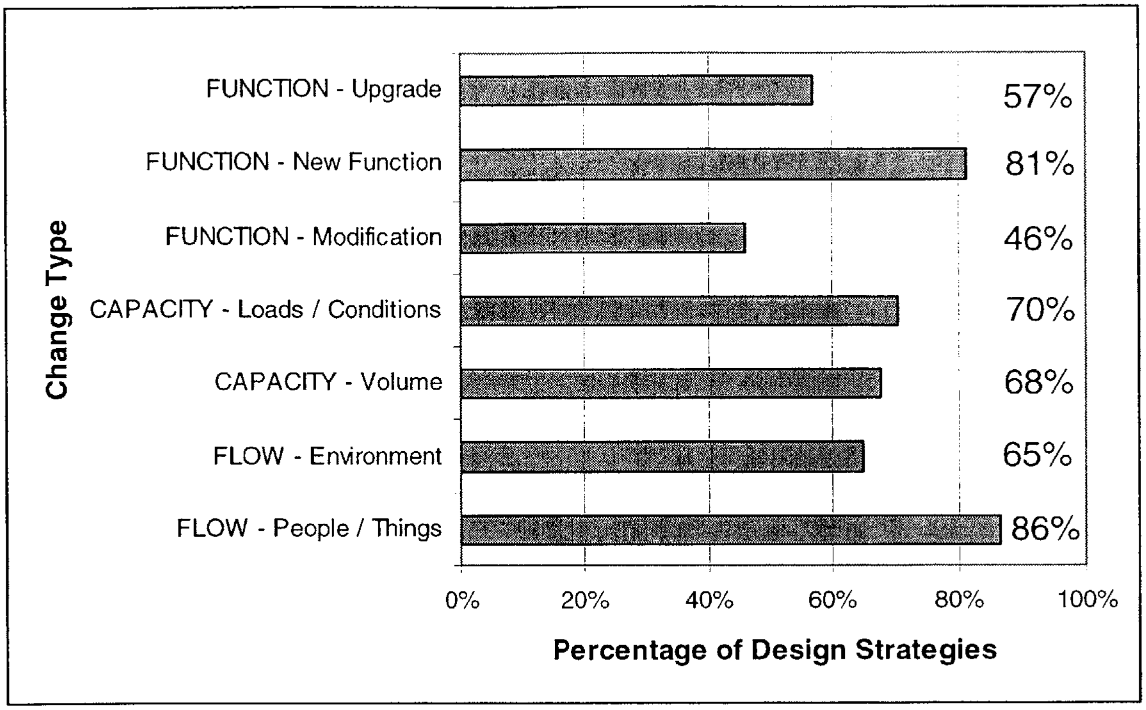


Figure 5.11 – Percentage of the sample (37 design strategies) that accommodates each change type

However, the reduced demolition activities allowed by the false slab also help to accommodate any change that requires access to the utilities (e.g., upgrade/repair of piping, or new piping for changes in loads, volume, and usage class). These changes may be accommodated by the strategy, regardless of whether or not the user takes advantage of the inherent flexibility.

5.2.2 Strategies and Building Systems

The matrix in Figure 5.12 displays the relationship between the building systems to which the design strategies are applied, and the building systems that achieve some level of flexibility as a result of the design strategies' use. A table showing the data that was used to generate this matrix can be found in Appendix C, Table C.2. As shown, eleven of the 37 strategies are applied to the structural system, two are applied to the enclosure, 22 to the service systems, and eleven to the finish systems (summed, these strategies exceed the total of 37, because some strategies are applied to two building systems). Of the 37 strategies, 11 achieve flexibility for the structural system, three for the enclosure, 30 for service systems, and 22 for finish systems (again, these strategies exceed the total of 37, because many strategies provide flexibility in more than one system). In the sample of strategies identified, there are a relatively very small number of design strategies that either are applied to or achieve flexibility in the enclosure system.

Along the diagonal of the matrix are strategies that are applied to a system and provide flexibility in that same system. There are expected to be high number of design strategies along this diagonal, since these designs are used to directly improve the flexibility of the system. In the areas not on the diagonal are design strategies that are applied to one system, yet achieve flexibility in another. While the highest concentrations of strategies fall on the diagonal of the matrix, a large number do not, indicating that significant flexibility can be achieved as a result of interactions between systems.

In Section 2.5.2 of this document, several statements identified in the literature review suggested that many design strategies would be encountered that focus on improving the flexibility of the services, while few will focus on the structure. However, while there were many strategies that focused on achieving flexibility in the services, 30% of the strategies improve flexibility in the structure. One expectation in particular, which is that the spatial structure (such as configuration, structure, and enclosure) influences flexibility *to a limited degree* (Glen, 1994), appears to be contradicted by the data. The statement implies that nearly all of the strategies identified should be located in the lower right-hand quadrant of the matrix (the intersections of Services and Finish). While this is the quadrant with the highest concentration of design strategies identified in the sample, the number of design strategies in the other areas of the matrix, especially in the upper left-hand quadrant, is significant.

Four areas of the matrix have large concentrations of design strategies that are not on the matrix diagonal. Fifteen strategies are applied to service systems to achieve flexibility in the finish systems. Twelve of these strategies allow flexibility in the finish systems by reducing the physical interactions between service and finish subsystems. Two allow flexibility by reducing spatial interactions (Small-area VAV units allow finish systems to be constructed without disrupting the HVAC flow, and task lighting systems allow finish systems to be built without worrying about interfering with the overhead light supply). The last strategy (extra-fast acting sprinklers) allows flexibility by allowing finish systems to be constructed from alternative materials that may not otherwise be allowed by fire code restrictions.

Nine strategies allow flexibility in the services by applying designs to the finish systems, eight of which do so by reducing physical interactions. The ninth (Room size standardization) increases predictability of the locations of services systems concealed behind walls, ceilings, and floors. Clearly, reducing spatial interactions provides a common means for improving flexibility in either the service or finish systems, by altering the other system.

Strategy Achieves Flexibility in System:	Strategy Applied to System: Structure	Enclosure	Services	Finish	Any
Structure	8 22%	1 3%	3 8%	1 3%	11 30%
Enclosure	1 3%	2 5%	1 3%	-	3 8%
Services	7 19%	-	22 59%	9 24%	30 81%
Finish	2 5%	-	15 41%	10 27%	22 59%
Any	11 30%	2 5%	21 57%	11 30%	Total 37

Figure 5.12 – Number of design strategies applied to a system (horizontal axis) and that achieve flexibility in a system (vertical axis)

Seven strategies are applied to the structural system to achieve flexibility in the building services. Two are strategies that limit demolition of the substructure to allow better access to the services concealed beneath the slab (False slab, Interstitial space beneath structural slab). Three strategies are different layouts that consolidate the service mains while providing a large, uninterrupted, regularly shaped space, throughout which the services are distributed. The final two strategies provide additional capacity in specific parts of the structure (Structural column overcapacity allows rooftop service equipment to be added; Oversized vertical shafts create larger incisions in the slab than are initially needed, to allow future vertical service distribution).

Finally, the three strategies that provide flexibility in the structure while being applied to the service systems are all strategies that consolidate the vertical distribution of the services. This allows alterations to be made to the structure (e.g., incisions in slabs to create new stairways) with minimal physical interference with service mains and distribution. Consolidating the vertical distribution at the time of initial construction appears to be a simple, effective way of allowing flexibility of the structure.

5.2.3 Strategies and Feasibility

Sixteen strategies had at least one of four identified types of restrictions on their use. Six strategies had *material type* restrictions, two were limited by *load capacity*, seven required certain *dimensions* in the building space, and three required that a special *component or system* be installed to make the strategy successful (Table 5.4). In Table 5.5, the systems in which the restrictions exist are identified with the restriction type for each strategy, as are the systems that are subject to the design strategy and require that the restriction be assuaged. Most strategies that are subject to restrictions are limited by the structural system, in its dimensions, material, or capacity to carry loads. Other strategies require a particular or general finish product to be installed (e.g., hung ceiling) in order for the strategy to be effective. The enclosure and service systems did not restrict the use of design strategies in the sample.

Restriction Type	Number of strategies
Material type	5
Load capacity	2
Dimensions	7
Component/system	3
Total	*17*

Table 5.4 – Number of strategies with one of four identified restriction types (Note: Sixteen strategies had restrictions. One strategy (False slab) is restricted by both the structural material type and the structural load capacity.)

Design Strategy	Strategy applied to system	Restriction type	Restricted by system
False slab	Structure	Material type (Concrete)	Structure
Exterior wall concrete knockout panels	Structure	Material type (Concrete)	Structure
Poke-through floors	Services	Material type (Concrete)	Structure
Structural "ladder" assembly system	Structure	Material type (Steel)	Structure
Column-free zones in structure	Structure	Material type (Steel)	Structure
Modular panel cladding system	Enclosure	Material type (Steel)	Structure
False slab	Structure	Load capacity	Structure
Interstitial mezzanine floor rack system	Structure	Load capacity	Structure
Interstitial mezzanine floor rack system	Structure	Dimensions	Structure
Z-layout configuration	Structure	Dimensions	Structure
Centralized configuration	Structure	Dimensions	Structure
Two-end core layout	Structure	Dimensions	Structure
Raised flooring	Finish	Dimensions	Structure
Access floor delivery system	Finish and Services	Dimensions	Structure
Access floors housing mechanical ducts	Finish and Services	Dimensions	Structure
Overhead cable trays	Services	Component (Hung ceiling)	Finish
Monoblock partition systems	Finish	Component (Hung ceiling)	Finish
Utility risers at columns	Services	Component (Raised floor)	Finish

Table 5.5 – Strategies that are restricted in their feasibility, the system to which each strategy is applied, the restriction type encountered by the strategy, and the corresponding system that creates the restriction

It is important to note the impact of interactions on feasibility. As shown, the structure tends to be the system that most limits the strategies from being effective, which upholds the statement by Brand (1994) that "the dynamics of a system will be dominated by the slow components, with the rapid components simply following along." That is, changes will often be limited by the structure because of its slow pace of change. For example, when raised flooring is installed in a building, the hard-finish areas (e.g., corridors, elevator landings) must be at the same height as the *top* of the raised floor (a structural dimension constraint). This makes installation of raised floors in renovation projects quite difficult, since the structural slabs may not be properly aligned to accommodate the raised panels. The structure's inability to change (or at least, it's strong resistance toward changing) to accommodate the raised floors restricts the use of the design strategy. This is the nature of buildings, and little can be done to provide flexibility in the structure to accommodate such needs. Some of these restrictions may be relieved when extra structural strength exists, and when the dimensions of the space are large and unconstrained.

5.2.4 The Value of Strategy Flexibility

In the following sections, the full sample of design strategies is examined for trends in characteristics that impact the effectiveness of a strategy over the life of a building. Common characteristics are presented, and strategies that are unique or that refute expectations are further examined.

5.2.4.1 Financial Costs

It is expected by some that designing for flexibility will always be very expensive. Increases in the initial construction cost of a building were found to vary over a wide range, but in fact, most created an increase in the building cost of less than 3%, and for over half the strategies, the cost increase was less than 1% (Table 5.6, Figure 5.13). Nine strategies were complex enough to make the changes in initial cost impossible to estimate closely, and are classified as "*Variable about zero.*"

	Initial Construction Costs	
Cost statistic	Increase in cost per square foot	Percent increase in building cost
Minimum cost increase	$0/sf	0%
Maximum cost increase	$20.55/sf	22.4%
Average cost increase	$1.49/sf	1.6%
Median cost increase	$0.18/sf	0.2%
Cost measure	Quantity of strategies	
Variable about zero	9	

Table 5.6 – Statistics of design strategies in the sample representing the impact on initial construction costs

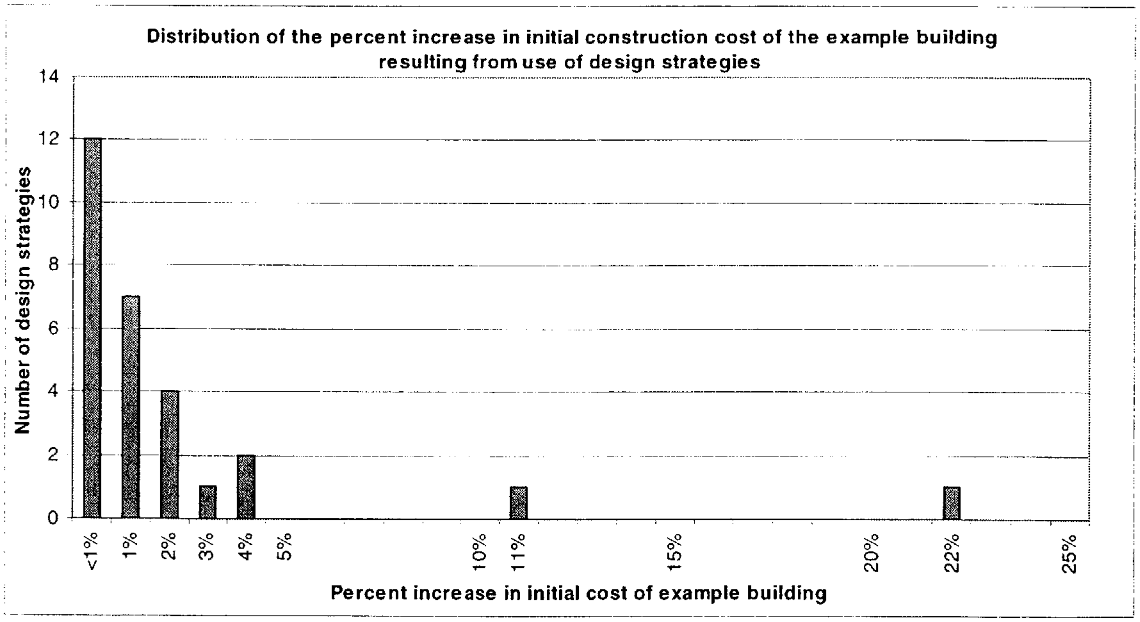


Figure 5.13 – Distribution of the percent increase in initial construction cost of the example building resulting from use of design strategies (Note: The nine strategies with initial cost increases classified as "Variable about zero" are excluded from this distribution.)

As expected, most strategies had no significant impact on the costs of operations and maintenance (Table 5.7). Only a few have positive or negative impacts on this phase of the life cycle, which are typically viewed as secondary costs or benefits. It was found that strategies are not likely to be implemented for the purposes of improving operations and maintenance costs, and likely did not anticipate increases in operations and maintenance activities. These cost increases are primarily due to higher densities of system components, which proportionally increase a system's required maintenance activities.

Operations and Maintenance Costs		
Cost measure	Quantity of strategies	Percent of sample
Decreased	5	14%
Not significant	19	51%
Increased	4	11%
Not applicable	9	24%

Table 5.7 – Impact of design strategies on operations and maintenance costs

Savings in the implementation of a change also varied over a large range, with the average savings equaling $14/sf, but with half the strategies saving between $2 and $5/sf (Table 5.8, Figure 5.14). Only one strategy had an increased cost (i.e., negative savings) result from implementing a change (Poke through floors are more expensive to create changes in wiring than conventional behind the wall techniques, but provide distribution to any location on a floor).

Some strategies yielded very large savings, however. One strategy identified created very large savings of $300/sf for implementing a change. (This strategy is an innovative overhead drainage system for grocery refrigeration units, which draws water upward under vacuum pressure and eliminates the need for under-the-slab drainage, eliminating nearly all demolition and reconstruction costs when the units are relocated.)

Change Implementation Costs	
Cost statistic	Savings in cost per square foot
Minimum cost savings	$-0.23/sf
Maximum cost savings	$300.00/sf
Average cost savings	$14.21/sf
Median cost savings	$2.25/sf
Cost measure	Quantity of strategies
Variable about zero	6
Alternative cost prohibitive	9

Table 5.8 – Statistics of design strategies in the sample representing the impact on change implementation costs

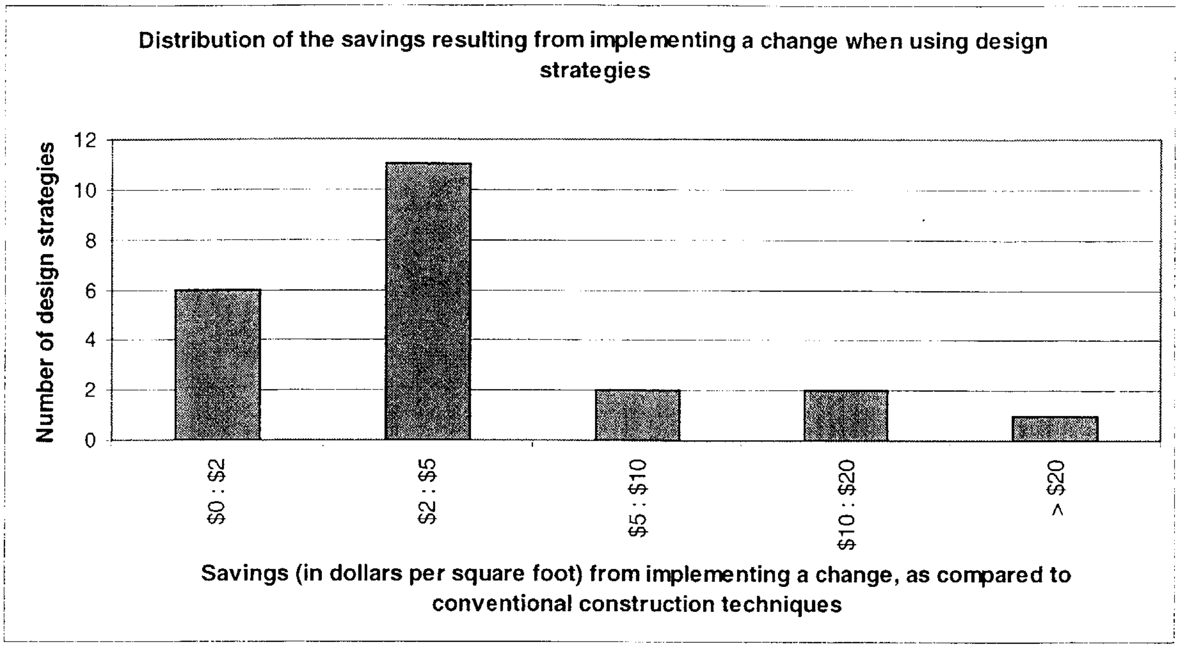


Figure 5.14 – Distribution of the savings resulting from implementing a change when using design strategies (Note: Fifteen of the 37 strategies have savings classified as "Variable about zero" or "Alternative is cost prohibitive," and are excluded from this distribution.)

Fifteen of the 37 strategies have no savings cost estimate. The six strategies classified "Variable about zero" could not be estimated absent a specific building context, and nine strategies had savings classified as *Alternative cost prohibitive,* for which no baseline cost data could be found to accurately determine the strategy's savings relative to a conventional alternative. These nine strategies are listed in Table 5.9, along with the associated changes that are enabled by using the strategy. All nine of these strategies have low impacts on the initial construction costs. The first four of these strategies enable changes in the structure, and achieve this by providing additional capacity in certain structural components. The fifth strategy uses a modular panel cladding system that costs approximately the same as a masonry enclosure, but allows individual panels to be removed quickly and cleanly so that exterior apertures (doors and windows) can be added, subtracted, or rearranged. The final four strategies enable the services to accommodate changes in layout at virtually no cost.

Strategies that enable changes not possible when using conventional construction techniques	Change enabled
1. Exterior wall concrete knockout panels	*Add aperture to structural wall*
2. Interstitial mezzanine floor rack system	*Insert floor(s)*
3. Structural "ladder" assembly system	*Strengthen floor(s)*
4. Structural column overcapacity	*Add additional floor(s)*
5. Modular panel cladding system	*Rearrange exterior apertures*
6. Small-area VAV units	*Control temperature in small areas*
7. Access floor delivery system	*Rearrange ventilation diffusers*
8. Task lighting system	*Concentrate lighting loads*
9. Access floors housing mechanical ducts	*Rearrange ventilation diffusers*
Average initial construction cost increase:	<1%
Range of initial construction cost increase:	0-2.5%

Table 5.9 – Strategies that enable changes not possible when using conventional construction techniques (savings classified *Alternative cost prohibitive*)

The benefit-to-cost ratio (BCR) of each strategy was found by dividing the expected savings per square foot by the initial construction cost increase per square foot. A BCR greater than or equal to one indicates a strategy whose savings offset its initial cost. It is important to note these ratios were calculated using the following assumptions: (1) cost and savings are based on dollar-per-square-foot estimates; (2) the desired change happens once throughout an entire building; and (3) costs and savings are not discounted for time. The distribution of these BCR's is shown in Figure 5.15. Strategies that have a cost or savings classified as either "Variable about zero" or "Alternative is cost prohibitive," or that have no initial cost increase are excluded from this distribution, since their BCR's are not calculable.

Five strategies have BCR's less than one, indicating strategies that would be considered economically unwise (Table 5.10). One of these strategies (Poke-through floors) does not provide any savings over its conventional alternative when changes are implemented; rather, its benefits are in the ability to distribute wires to any location on a floor independent of the layout of finish systems. The other four strategies allow changes that are expected to occur often, and will become cost effective after a series of several changes has been implemented.

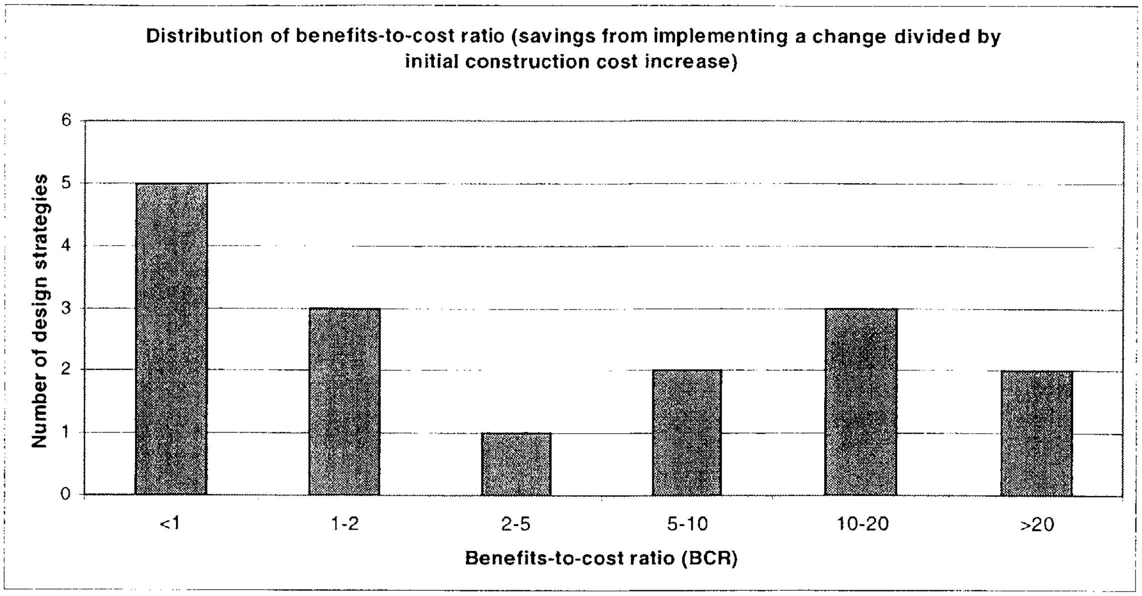


Figure 5.15 – Distribution of the benefits-to-cost ratio (BCR) for the full sample of design strategies (Note: Strategies that have a cost or savings classified as either "Variable about zero" or "Alternative is cost prohibitive," or that have no initial cost increase are excluded from this distribution, since their BCR's are not calculable.)

Design strategies with BCR's less than 1		
Strategy	BCR	Number of change required to make strategy cost effective
1. Poke-through floors	0	-
2. Office pod system	0.24	5
3. Interstitial space beneath structural slab	0.34	3
4. Demountable mid-height partitions	0.56	2
5. Monoblock partition systems	0.56	2

Table 5.10 - Design strategies with BCR's less than 1, their corresponding BCR's, and the number of changes required to make each strategy cost effective

Eleven strategies have BCR's greater than one, indicating that the strategy is cost effective after just one change throughout the entire building (Table 5.11).

Design strategies with BCR's greater than 1	
Strategy	**BCR**
1. Raised flooring	1.2
2. Overhead cable trays	1.4
3. Demountable full-height partition walls	1.5
4. Single/multi-channel surface raceways	2.9
5. False slab	5.8
6. High density of electrical outlets	8.8
7. Extra fiberoptic lines	13
8. Enhanced performance cabling system	13
9. Exposed ceilings with overhead distribution	14
10. Extra vacant conduit	48
11. Overhead drainage system	620

Table 5.11 - Design strategies with BCR's less than 1.0 and their corresponding BCR's

Two strategies that have no initial cost increase and positive savings are listed in Table 5.12. The site-fixed panel partitions can be installed at approximately the same cost as conventional drywall partitions, but reduce demolition activities when access behind the walls is needed to implement a change. The extra-fast acting sprinklers allow certain materials that might otherwise not be allowed to finish a space because of fire code restrictions, and the cost difference over the use of normal sprinkler heads is negligible.

Strategies with no initial cost increase and positive savings from implementing a change	
Design strategy	Savings per square foot
1. Site-fixed panel partition system	$2.25/sf
2. Extra fast acting sprinklers	$5.36/sf

Table 5.12 - Strategies with no initial cost increase and positive savings from implementing a change

One might expect that savings realized during the implementation of a change would be proportional to the amount of increase in initial cost (i.e., savings at a later date have costs at the time of initial construction). This is supported by the data in Table 5.13, which shows that design strategies that result in a savings of $1/sf or greater have a higher initial cost increase than design strategies that result in lesser savings. However, as discussed earlier in this section, the nine strategies that enable changes that would be cost prohibitive using conventional designs have a low impact on initial construction costs.

Expected savings per square foot during change implementation	Number of strategies	Average initial construction cost increase
Less than $1/sf savings	6	1%
$1/sf savings or more	16	2%
Alternative is cost prohibitive	9	<1%

Table 5.13 – Comparison of initial construction cost and savings during change implementation

5.2.4.2 Initial Construction Duration and Downtime Resulting from Change Implementation

The two measures of initial construction duration and downtime account for impacts resulting from the length of time of construction activities. Table 5.14 shows the relationship between the construction duration and initial construction cost.

In construction it is commonly said that for the project objectives of time, cost, and quality, only two factors can be accommodated at a time (i.e., construction that is quick and inexpensive will generally have poor quality, construction that is fast and of high quality will be expensive, and construction that is inexpensive and of high quality will take a long time). Assuming that quality is constant, the construction duration and construction cost are expected to be inversely related. The data in Table 5.14 supports this theory. The average increase in construction cost is greater for designs that do not impact the construction duration than for those that have a lengthened duration. Of the three strategies that shorten the initial construction duration, two are not exceptions to the theory (one reduces the material used, then completes installation at a later date, and the other uses lower-quality materials). The third design strategy is an innovative wiring system that reduces the time to make connections, without reducing quality or significantly increasing costs.

Construction duration	Number of strategies	Percent of sample	Average percent increase in initial cost
Shortened	3	8%	0%
No impact	23	62%	2%
Lengthened	11	30%	1%

Table 5.14 – Correlation between initial construction duration and increase in initial cost

In Table 5.15, the theory that cost and time are inversely related is again supported. Generally, using a design strategy that increases the cost of initial construction allows the time to implement a change at a later date to be shortened. No strategies in the sample lengthened the downtime to implement changes.

Downtime to implement change	Number of strategies	Percent of sample	Average percent increase in initial cost
Shortened	26	70%	2%
No impact	11	30%	1%
Lengthened	-	-	-

Table 5.15 – Correlation between downtime resulting from change implementation and increase in initial cost

The correlation between initial construction duration and downtime resulting from change implementation is shown in Table 5.16. It can be seen in this figure that most design strategies in the sample shorten the downtime resulting from change implementation, regardless of whether or not they impact the initial construction.

Downtime Resulting from Change Implementation	Initial Construction Duration		
	Shortened	*No impact*	*Lengthened*
Shortened	3	15	8
No impact	-	8	3
Lengthened	-	-	-

Table 5.16 – Correlation between initial construction duration and downtime resulting from change implementation

5.2.4.3 Accessibility for Operations and Maintenance and Accessibility for Renovation

The accessibility for operations and maintenance is compared to the average increase in initial cost in Table 5.17. The difference in cost between strategies that improve accessibility and those that do not have any impact is small. The large increase in cost for strategies that adversely effect accessibility is a result of the small size of the sample portion. This strategy (office pod system) has a very high initial construction cost and may worsen accessibility by placing service connections in inaccessible locations.

Accessibility for operations and maintenance	Number of strategies	Percent of sample	Average percent increase in initial cost
Improved	19	51%	1%
No change	12	32%	1%
Worsened	1	3%	22.4%
Not applicable	5	14%	<1%

Table 5.17 – Correlation between accessibility for operations and maintenance and increase in initial cost

The five strategies that have no operations and maintenance costs associated with either the design strategy or the conventional alternative (classified as *Not applicable* in Table 5.17) are listed in Table 5.18. All five strategies provide extra capacity in some system (three to the structure, two to services), which will not require operations or maintenance activities (e.g., in the first strategy, extra reinforcing steel, which requires no maintenance is embedded in certain areas of structural concrete walls).

Strategies classified as *Not applicable* for accessibility considerations
1. Exterior wall concrete knockout panels
2. Structural "ladder" assembly system
3. Structural column overcapacity
4. Extra fiberoptic lines
5. Extra vacant conduit

Table 5.18 - Strategies that have no operations and maintenance costs associated with either the design strategy or the conventional alternative

Table 5.19 illustrates the relationship between accessibility for renovation and initial cost. Here, the strategies that improve accessibility for renovation are much cheaper than are those that do not change accessibility, implying that this type of accessibility can be achieved relatively cheaply.

Accessibility for renovation	Number of strategies	Percent of sample	Average percent increase in initial cost
Improved	24	65%	1%
No change	13	35%	3%
Worsened	-	-	-

Table 5.19 – Correlation between accessibility for renovation and increase in initial cost

Table 5.20 shows that accessibility for operations and maintenance and accessibility for renovation are closely related to one another, since the majority of design strategies (25 of 32 applicable strategies) have the same level of impact on both renovation and operations and maintenance. Of the five strategies that improve accessibility for renovation but not for operations and maintenance, four are designs applied to the layout of a building plan that accommodate quick gut-and-replace renovations. The one strategy that improves accessibility for operations and maintenance but not for renovations distributes the service mains along corridors in a building, providing access for maintenance without disturbing operations in rooms along the corridors. One strategy (Office pod system) inhibits the accessibility of the services by locating service interfaces between the roof of the pods and the ceiling of the main structure (during renovation, the pods are disassembled, and the services interfaces are then exposed).

Accessibility for renovation	Accessibility for operations and maintenance			
	Improved	*No impact*	*Worsened*	*Not applicable*
Improved	17	5	-	1
No impact	1	8	1	4
Worsened	-	-	-	-

Table 5.20 – Correlation between accessibility for operations and maintenance and accessibility for renovation

5.2.4.4 Procurement Concerns and Irrevocability of Commitment

It is expected that design strategies classified as having procurement concerns (i.e., those that involve the use of unconventional materials) generally have higher costs, based on the belief that unconventional materials and components will be more difficult to procure than conventional building materials. Figure 5.16 shows that this relationship is generally true within the sample, since most strategies with large increases in initial cost tend to have procurement concerns, while most strategies with small initial cost increases tend not to have procurement concerns. However, it should be noted that over half of the strategies with procurement concerns increase the initial construction cost of a building by less than 1%.

Commitment to a design strategy is characterized by the cost to replace a system affected by a design strategy, in the event of the strategy's failure. The level of commitment to a design strategy is compared to the increase in initial construction cost in Table 5.21. As shown, strategies with a significant level of commitment (i.e., a new design can be used, but only at a major cost) have significantly higher initial costs than those with no commitment (i.e., a new design can be

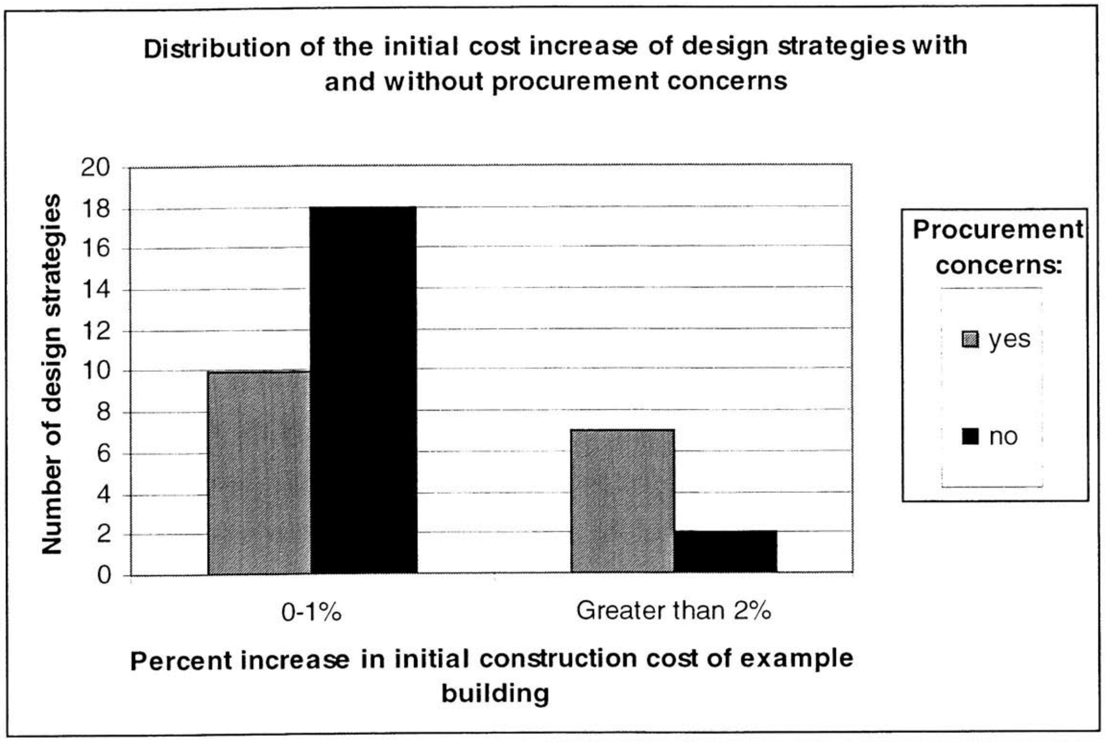


Figure 5.16 – Distribution of the initial cost increase of design strategies with and without procurement concerns

used at a minor cost). The strategies that require a total commitment (i.e., the design cannot be replaced affordably) are, however, not expensive to use initially.

Irrevocability of commitment	Number of strategies	Average percent increase in initial cost
None	5	<1%
Significant	18	2.5%
Total	14	1%

Table 5.21 – Correlation between irrevocability of commitment and increase in initial cost

Clearly, most design strategies require at least a significant level of commitment. Five strategies do not require any commitment (Table 5.22). All five of these strategies involve the installation of system components that remain dormant until used, and can be simply ignored if their use is not desired.

Strategies which require no significant commitment
1. Exterior wall concrete knockout panels
2. Interstitial mezzanine floor rack system
3. Extra fiberoptic lines
4. High density of electrical outlets
5. Extra vacant conduit

Table 5.22 – Strategies that require no significant commitment

The high costs of the "middle" measurement of commitment (i.e., significant commitment) can be explained by the correlation between procurement concerns and irrevocability of commitment within the sample (Table 5.23). As shown, there is a strong correlation between strategies with a significant level of commitment and strategies that have procurement concerns, which tend to have higher costs than other strategies. Similarly, there is a strong correlation between strategies with total commitment to the design and strategies that have no procurement concerns, which tend to have relatively lower costs.

Procurement concerns	Irrevocability of commitment		
	None	*Significant*	*Total*
Yes	1	13	3
No	4	5	11

Table 5.23 – Correlation between procurement concerns and irrevocability of commitment

5.2.4.5 Safety Concerns

The four leading hazards that account for the most serious injuries and fatalities in the construction industry are falls, electrical hazards, caught in/between hazards, and "struck-by" hazards (Lapping, 1997). Since the design strategies often do not require a specific erection process, these individual hazards may be mitigated with proper planning. Lack of planning and engineering oversight are found to be primary contributors to the cause of major failures on constriction sites (Lapping, 1997), and are not design-strategy-dependent characteristics. It is therefore not surprising that no strategies were encountered that create safety concerns for the construction, operations and maintenance, or change implementation stages.

5.2.5 Design Approaches and Clusters

The results from analysis of the design approaches and clusters of strategies listed in Table 3.1 are presented in this section. The strategies that appear in each cluster are displayed in Table 5.24. Recall that strategies were clustered by their general means by which they achieve flexibility in a building system. These clusters of strategies were then examined for trends in the data that differentiated the cluster from the other design strategies in the sample.

	Design Approach			Design Strategy Cluster										
Design strategy	Prefabricate major system components	Design to over capacity	Separate systems	Reduce intersystem interactions	Reduce intrasystem interactions	Use interchangeable system components	Increase predictability	Improve physical access	Dedicated volume for system zoning	Phase system installation	Simplify demolition	Enhance proximity	Improve flow through system layout	Number of strategy appearances
False slab								x	x		x	x		4
Exterior wall concrete knockout panels		x					x				x			3
Interstitial mezzanine floor rack system	x				x	x				x				4
Z-layout configuration							x						x	2
Structural "ladder" assembly system										x				1
Centralized configuration							x						x	2
Single/multi-channel surface raceways	x		x	x			x	x	x		x			7
Overhead cable trays	x		x	x			x	x	x		x			7
Structural column overcapacity		x								x	x			3
Oversized vertical distribution shafts		x		x	x			x			x			5
Two-end core layout							x						x	2
Raised flooring	x		x	x		x		x			x	x		7
Demountable mid-height partitions	x		x	x	x	x			x		x			7
Demountable full-height partition walls	x		x	x	x	x					x			6
Monoblock partition systems	x		x	x	x	x					x			6
Site-fixed panel partition systems				x	x	x		x	x		x			6
Utility risers at columns							x					x		2
Room size standardization							x						x	2
Column-free zones in structure		x	x	x										3
Office pod system	x		x	x		x					x			5
Modular panel cladding system	x		x	x	x	x		x			x			7
Accessible modular wiring	x				x	x					x			4
Poke-through floors								x				x		2
Exposed ceilings with overhead distribution			x	x			x	x			x			5
Extra fiberoptic lines		x					x					x		3
Street layout							x					x	x	3
High density of electrical outlets		x					x					x		3
Small-area VAV units		x					x					x		3
Access floor delivery system	x		x	x		x		x			x	x		7
Task lighting system	x				x	x						x		4
Access floors housing mechanical ducts				x		x		x			x	x		5
Enhanced performance cabling system		x												1
Interstitial space beneath structural slab				x				x	x		x			4
Overhead drainage system	x		x					x			x			4
Extra vacant conduit		x		x							x			3
Extra-fast acting sprinklers		x												1
High density of vertical shafts		x										x		2
Number of strategies in cluster	13	11	12	16	9	12	13	13	6	3	20	12	5	
Percent of sample	35.1%	29.7%	32.4%	43.2%	24.3%	32.4%	35.1%	35.1%	16.2%	8.1%	54.1%	32.4%	13.5%	

Table 5.24 – Design strategies that appear in each of the design approach and design strategy clusters

The general means clusters identified for achieving flexibility were not mutually exclusive. In fact, there was a significant amount of overlap between the clusters, with some design strategies appearing in as many as seven clusters (Table 5.24). Analyzing the data at the design strategy level appeared to be a more effective means for identifying relationships among characteristics.

However, analysis by cluster did provide a means to confirm or refute expectations about strategies that use a certain means for achieving flexibility.

Descriptions of each design approach and cluster of design strategies are given in the following sections, including an example for each group. The expectations for each cluster are explained and then checked against the actual data for each strategy in the cluster. Strategies that refute the expectations set forth are examined more thoroughly, and strategies with exceptional characteristics are identified. Characteristics that are not relevant to the expectations were also examined to identify unintended benefits and/or consequences.

5.2.5.1 Design Approach: Prefabricate Major System Components

Twelve strategies follow the general approach of prefabricating major system components. Seven strategies are applied to the services and seven to the finish systems, while only one is applied to the structure and one to the enclosure system. In Figure 5.17, an example is shown, in which interior partitions are prefabricated in a factory, then erected and joined on site to create interior wall systems.

Prefabricated components are expected to create procurement concerns, since components are often obtained through a specialized vendor, rather than through conventional material suppliers, and may also be constructed of unconventional materials that may be difficult for a vendor to procure in a timely manner. Prefabricated components are expected to have reduced interactions among each other, leading to reductions in the necessary time and money needed to implement changes. One also expects that the time for initial construction will be shortened on-site, because of the off-site construction activities, and that the prefabricated components will require some special skills or training of the constructor.

DESIGN APPROACH:
PREFABRICATE MAJOR
SYSTEM COMPONENTS

<u>Design Strategy</u>: Monoblock
Partition Systems

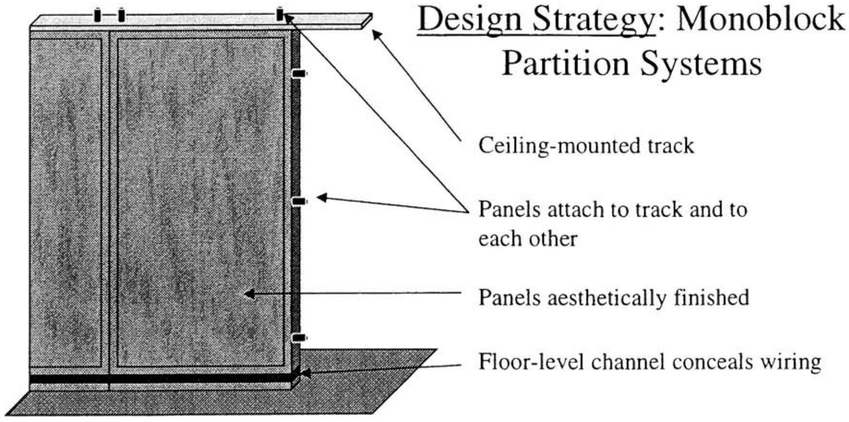


Figure 5.17 – Example of a design strategy that achieves flexibility through prefabrication of major system components

As expected, nearly all these strategies involve the use of specialty materials or components that create procurement concerns (Table 5.25), leading to an average increase in initial cost that is slightly higher than the average of the whole sample. The single exception is the task lighting system, which used conventional components in new configurations.

Design Approach: Prefabricate Major System Components		
Initial construction procurement concerns		Percent increase in initial building cost
Yes	*No*	
12	1	3%

Table 5.25 – Procurement concerns and initial construction cost increase of strategies that involve prefabrication of major system components

The downtime resulting from implementing a change is shorter for all thirteen strategies in this cluster, and the savings resulting from implementing a change is generally higher than for strategies in the rest of the sample (Table 5.26).

Design Approach: Prefabricate Major System Components			
Downtime resulting from implementing a change		Savings resulting from implementing a change	
No impact	*Shortened*	*Less than $1/sf*	*More than $1/sf*
0	13	1	12

Table 5.26 – Characteristics related to change implementation for strategies that involve prefabrication of major system components

In the entire sample of 37 design strategies, only three strategies were identified that shortened the construction duration (Table 5.27). All three of these strategies are found in this cluster. However, the other ten projects do not shorten initial construction, two of which (Raised flooring, Overhead drainage system) actually make construction take longer than their conventional alternative. Seven of the 13 (54%) strategies in this cluster do require special skills of the constructor, which is significant, since only ten of the 37 strategies in the whole sample (27%) require special skills.

Design Approach: Prefabricate Major System Components				
Initial construction duration			Ease of initial construction	
Shortened	*No impact*	*Lengthened*	*Easy*	*Difficult*
3	8	2	6	7

Table 5.27 – Significant characteristics related to initial construction for strategies that involve prefabrication of major system components

5.2.5.2 Design Approach: Design Over Capacity

Strategies in this cluster typically accommodate changes by adding capacity in the system at a time when the incremental change in materials and/or labor is affordable, so that little or no construction activities are necessary for implementing a change. Of these eleven strategies, the majority (seven) are applied to service systems, while four are applied to the structural system, and one to the enclosure. No strategies were identified that are applied to the interior finish systems, which makes sense, since providing extra walls or layers of carpeting would be silly, and few owners would identify finish systems with a high resistance to wear and tear (i.e., extra load capacity) as a design strategy. Figure 5.18 illustrates two examples of these strategies. Installing a *high density of electrical outlets* allows rearrangement of components in the electrical systems without rewiring, and *exterior concrete knockout panels* allow an aperture to be cut into a load-bearing concrete wall without strengthening the wall at the time of the change.

Strategies in this cluster are expected to be built from conventional materials and components that have few procurement concerns. A low level of complexity is also expected, since this approach usually involves simply making components and design attributes larger or stronger. Both of

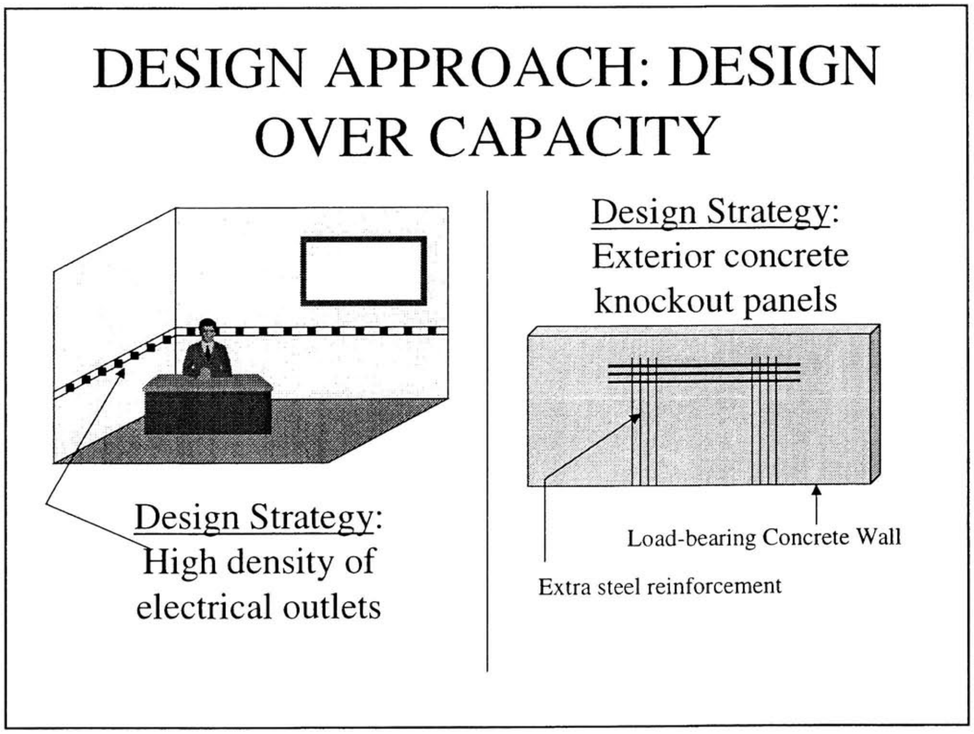


Figure 5.18 – Examples of design strategies that achieve flexibility through designing over capacity

these findings are supported by the data, which is shown in Table 5.28 and Table 5.29. The two strategies with procurement concerns are the enhanced performance cabling systems and extra-fast acting sprinklers, which require special components that may be difficult to procure. The one strategy that complicates design and construction activities is the elimination of structural columns throughout zones in the structure.

Design Approach: Design Over Capacity		
Initial construction procurement concerns		Percent increase in initial building cost
Yes	*No*	
2	9	1%

Table 5.28 – Procurement concerns and initial construction cost increase of strategies that achieve flexibility through excess capacity in building systems

Design Approach: Design Over Capacity			
Initial design difficulty		Initial ease of construction	
Simple	*Difficult*	*Easy*	*Difficult*
10	1	10	1

Table 5.29 – Significant characteristics related to design and construction complexity of strategies that achieve flexibility through excess capacity in building systems

It is often assumed that designing over capacity will lead to large increases in construction cost. The cost data in this cluster tells a different story, however, showing only a small increase in the initial construction cost (Table 5.28). In fact, following this approach seems to be of unexpectedly very high value, as indicated by the concentration of high benefit-to-cost ratios for the strategies in this cluster (Table 5.30). In particular, three strategies enable changes that would be cost prohibitive if conventional designs were used (i.e., exterior wall concrete knockout panels allow apertures to be cut into structural concrete walls, structural column overcapacity allows additional floors to be added to a structure without having to strengthen columns, and small-area VAV units allow for local control of temperature within a space). Owners would do well to specify that their building systems incorporate some additional capacity beyond what is immediately needed.

Design Approach: Design Over Capacity	
Benefit to cost ratio (BCR)	Number of strategies
<1	-
1-2	-
2-5	-
5-10	1
10-20	2
>20	1
Variable about zero	3
Zero cost, with positive savings	1
Alternative cost prohibitive	3

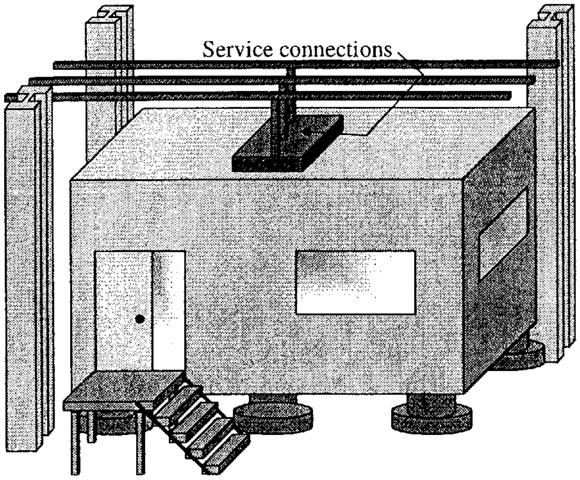
Table 5.30 – Distribution of benefit to cost ratios for strategies that follow the approach of designing over capacity

5.2.5.3 Design Approach: Separate Major Building Systems

Several strategies achieve flexibility by eliminating some physical interactions between building systems that would occur when using conventional construction techniques. Of these 12 strategies, four are applied to the finish systems, two to service systems, and four to both service and finish, while only one strategy is applied to the structure and one to the enclosure. In Figure 5.19, the *office pod* strategy creates a module containing all the finish systems, which connects to the services at only a single interface point.

Using the strategies in this cluster, one might expect to see improvements in the accessibility of the systems and components for either operations and maintenance or renovation. While most of the strategies do provide better accessibility, there does not appear to be a greater proportion of strategies that achieve better accessibility in this cluster than in the entire sample of design strategies (Table 5.31).

DESIGN APPROACH: SEPARATE MAJOR BUILDING SYSTEMS



Design Strategy:
Office Pod Systems

Figure 5.19 – Example of a design strategy that achieves flexibility through separating building systems

Design Approach: Separate Major Building Systems					
Accessibility for operations and maintenance			Accessibility for renovation		
Improved	*No impact*	*Worsened*	*Improved*	*No impact*	*Worsened*
8	3	1	8	4	0

Table 5.31 – Characteristics related to accessibility for strategies that involve the separation of major building systems

Physically separating the systems is expected to take longer than normal construction techniques, but reduce the downtime due to implementing a change. The shortened downtime is reflected in the data (Table 5.32), but surprisingly, very few of these strategies lengthen initial construction.

Design Approach: Separate Major Building Systems				
Initial construction duration			Downtime resulting from implementing a change	
Shortened	*No impact*	*Lengthened*	*No impact*	*Shortened*
1	9	2	1	11

Table 5.32 – Significant characteristics of strategies that involve the separation of major building systems

Most of these strategies have surprisingly simple designs (Table 5.33). Eleven of the 12 strategies that follow this approach (92%) achieve the separation of building systems by using unconventional components or materials with procurement concerns, which was not an obvious expectation. These unconventional materials lead to initial construction cost increases that are higher than most strategies identified in the whole sample (Table 5.33). The single strategy (Column-free zones in structure) that separates systems (structure and finish) without procurement concerns can be quite costly and difficult to design.

Design Approach: Separate Major Building Systems				
Design difficulty		Initial construction procurement concerns		Percent increase in initial building cost
Simple	*Difficult*	*Yes*	*No*	
7	5	11	1	4%

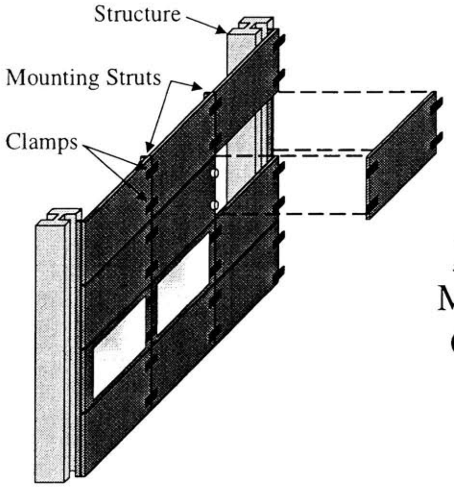
Table 5.33 – Design difficulty, procurement concerns, and initial construction cost increase of strategies that involve the separation of major building systems

5.2.5.4 Cluster: Reduce Intersystem Interactions

Sixteen strategies were identified that *Reduce Intersystem Interactions.* Strategies in this cluster reduce physical, spatial, or functional interactions between systems, rather than eliminating just the physical interactions, as in the previous design approach. As in the *"Separate Major Building Systems"* approach, the majority of the strategies here are applied to the interior finish and service systems (i.e., two strategies are applied to service systems, four to the finish, and four to both services and finish), while only two design strategies are applied to the enclosure and one to the structure. The *modular panel cladding system* illustrated in Figure 5.20 shows how connections between the enclosure and structural systems can be effectively reduced.

It is expected that intersystem interactions might be reduced by using special products, which would create procurement concerns and higher initial cost increases. One would also expect that strategies that reduce interactions between systems would improve accessibility, leading to shortened downtime and increased savings from implementing changes.

CLUSTER: REDUCE INTER-
SYSTEM INTERACTIONS



Design Strategy:
Modular Panelized
Cladding System

Figure 5.20 – Example of a design strategy that achieves flexibility through reducing interactions between building systems

Twelve of the 16 strategies in this cluster do have procurement concerns, but there are four that do not (Table 5.34). These four strategies focus on reducing the physical and spatial interactions between systems by providing a dedicated space for service distribution, or isolating the structure from the finish systems.

Cluster: Reduce Intersystem Interactions		
Procurement concerns		Percent increase in initial building cost
Yes	*No*	
12	4	3%

Table 5.34 – Procurement concerns and initial construction cost increase of strategies that involve the reduction of interactions between systems

As expected, accessibility for operations and maintenance and for renovation are each improved in eleven of the sixteen strategies, which is higher than in the full sample (Table 5.35). The exception is the office pod system, as discussed in Section 5.2.4.3.

Cluster: Reduce Intersystem Interactions					
Accessibility for operations and maintenance			Accessibility for renovation		
Improved	*No impact*	*Worsened*	*Improved*	*No impact*	*Worsened*
11	3	1	11	5	0

Table 5.35 – Significant characteristics related to accessibility for strategies that involve the reduction of interactions between systems

During the implementation of changes, downtime is shortened in more than 85% of the strategies in this cluster, and savings are increased in over 80% of the strategies, as expected (Table 5.36).

Cluster: Reduce Intersystem Interactions			
Downtime resulting from implementing a change		Savings resulting from change implementation	
No Impact	*Shortened*	*<\$1/sf*	*>\$1/sf*
2	14	3	13

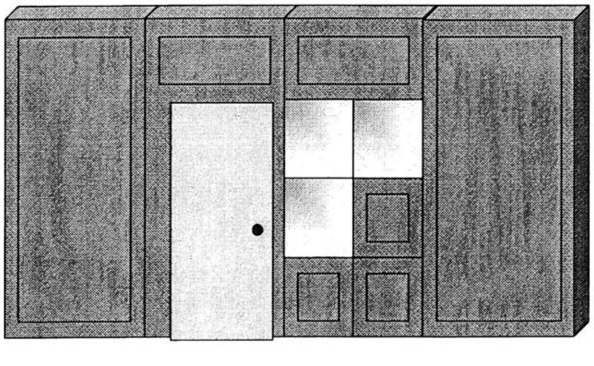
Table 5.36 – Significant characteristics related to implementing changes of strategies that involve the reduction of interactions between systems

5.2.5.5 Cluster: Reduce Intrasystem Interactions

Rather than reducing physical, spatial, and functional interactions between building systems, many strategies reduce interactions *within* a single building system. The interactions reduced are usually physical interactions. The example in Figure 5.21 shows a partition system that is broken down into modular components that can be easily joined and separated in many layout configurations. None of these strategies in this cluster are applied to multiple systems, which is expected, since these strategies target interactions within a single system. Two strategies are applied to the structure, one to the enclosure, two to services and four to the interior finish. Eight of the nine strategies reduce intrasystem interactions by simplifying the connections between components. The ninth strategy (Oversized vertical distribution shafts) reduces spatial interactions between the distribution components within service systems.

It can be expected that strategies that reduce the interactions within systems will shorten downtime and increase savings at the time of change implementation. As shown in Table 5.37, the downtime for implementing a change is reduced in all of the nine strategies.

CLUSTER: REDUCE INTRA-SYSTEM INTERACTIONS



Design Strategy:
Arrangeable monoblock partitions

Figure 5.21 – Example of a design strategy that achieves flexibility through reducing interactions within a single building system

Cluster: Reduce Intrasystem Interactions				
Downtime resulting from change implementation			Savings resulting from change implementation	
Shortened	*No impact*	*Lengthened*	*<$1/sf*	*>$1/sf*
9	0	0	2	7

Table 5.37 – Significant characteristics related to change implementation for strategies that involve the reduction of interactions among components within a single system

Many building products exist in the market that reduce the interactions between system components (e.g., Raised access floors, Modular partition systems, Modular wiring). It is therefore expected that many strategies in this cluster will have procurement concerns, and a correspondingly high cost. However, the average cost of these strategies is slightly lower than the average for the entire sample, in spite of the fact that seven of the nine strategies do have procurement concerns (Table 5.38), indicating that the benefits shown in Table 5.37 can be achieved affordably.

Cluster: Reduce Intrasystem Interactions		
Procurement concerns		Percent increase in initial building cost
Yes	*No*	
7	2	1%

Table 5.38 – Procurement concerns and initial construction cost increase of strategies that involve the reduction of interactions among components within a single system

5.2.5.6 Cluster: Use Interchangeable System Components

Strategies in this cluster use modular components that may be interchanged with one another to make changes in the system layout. Eight strategies are applied to the finish and five to the service systems, while only one strategy each is applied to the structural and enclosure systems. Figure 5.22 shows a raised panelized floor with data interface boxes attached to selected panels in the system. These panels may be interchanged to relocate a data box when necessary.

Since these modular components are often prefabricated and supplied by a specialty vendor, procurement concerns are expected to be significant, leading to higher costs and a high level of commitment to the strategies. During change implementation, reduced downtime is expected, and savings are expected to be high, because of the availability of reusable materials. Because these components are removable and interchangeable, it is expected that they may improve accessibility to other systems for operations and maintenance and for renovation. All of these findings are supported by the data in Tables 5.39, 5.40, 5.41, and 5.42.

CLUSTER: USE
INTERCHANGEABLE
SYSTEM COMPONENTS

<u>Design Strategy</u>: Raised Panelized Floor

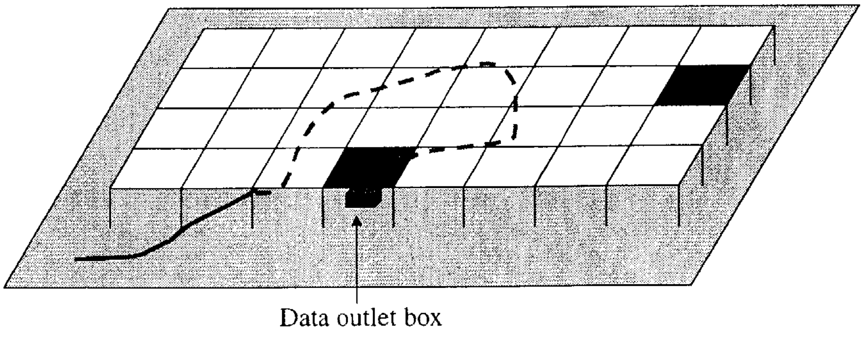


Figure 5.22 – Example of a design strategy that achieves flexibility through the use of interchangeable system components

Cluster: Use Interchangeable System Components		
Initial construction procurement concerns		Average increase in initial building cost
Yes	*No*	
11	1	3%

Table 5.39 – Procurement concerns and initial construction cost increase of strategies that involve the use of interchangeable system components

Cluster: Use Interchangeable System Components		
Irrevocability of commitment		
None	*Significant*	Total
1	8	3

Table 5.40 – Level of commitment of strategies that involve the use of interchangeable system components

Cluster: Use Interchangeable System Components					
Accessibility for operations and maintenance			Accessibility for renovation		
Improved	*No impact*	*Worsened*	*Improved*	*No impact*	*Worsened*
7	4	1	7	5	0

Table 5.41 – Significant characteristics related to accessibility for strategies that involve the use of interchangeable system components

Cluster: Use Interchangeable System Components				
Downtime resulting from change implementation			Savings resulting from change implementation	
Shortened	*No impact*	*Lengthened*	*<$1/sf*	*>$1/sf*
12	0	0	1	11

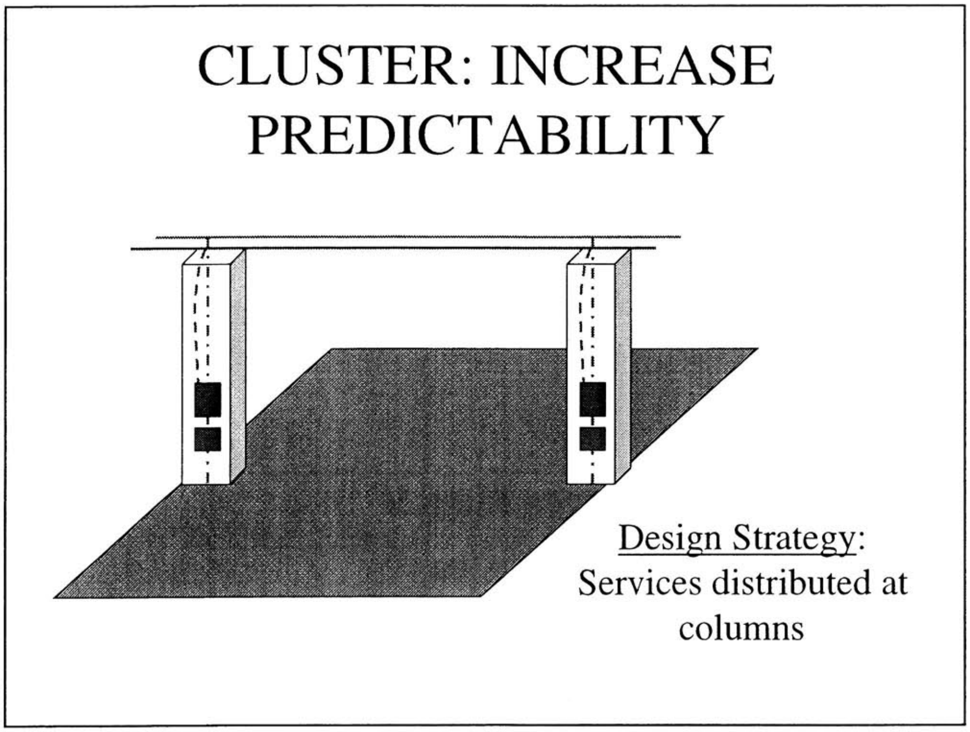
Table 5.42 – Significant characteristics related to change implementation for strategies that involve the use of interchangeable system components

The one strategy that presents no procurement concerns is the task lighting system, which uses conventional components in new configurations, and the single strategy that worsens accessibility is the office pod system. The interstitial mezzanine floor strategy does not have the high level of commitment expected of strategies in this cluster, and the modular wiring systems have relatively low savings compared to their conventional alternatives.

5.2.5.7 Cluster: Increase Predictability

Increasing a system's predictability eliminates exploration and demolition activities typically required for creating the physical access necessary to implement changes in conventional systems. Predictability is expected to be needed most for the structure and service systems, since these systems are often enclosed in and hidden behind layers of interior finish. Services are expected to undergo more frequent changes than the structure in most facilities. As expected, the majority of the strategies in this cluster are applied to the service systems (i.e., of 13 strategies in the cluster, seven are applied to the services and two to both services and finish, while four strategies are applied to the structure, three to finish systems, and one to the enclosure). Four strategies are applied to the structure, three to finish systems, and one to the enclosure. Figure 5.23 shows a system where services are distributed underneath a raised floor, with terminals at each column, eliminating guesswork in locating the services beneath the floor or inside partitions at the time of change implementation.

Since predictability can be increased by simply altering the layout or configuration of one or more systems (i.e., without the use of unconventional materials), few procurement concerns are



CLUSTER: INCREASE PREDICTABILITY

Design Strategy: Services distributed at columns

Figure 5.23 – Example of a design strategy that achieves flexibility through making system connections more predictable

expected. Complexity levels for design and construction are expected to be low, and accessibility is expected to improve for renovation, and for operations and maintenance.

The cost data in Table 5.43 indicates that this cluster is grouping of relatively inexpensive design strategies. Only three have procurement concerns, and the average cost increase of these strategies is very low. As expected, these strategies have low levels of both design and construction complexity (Table 5.44). The exception is the *utility risers at columns* design strategy, which has a high level of design difficulty.

Cluster: Increase Predictability		
Initial construction procurement concerns		Percent increase in initial building cost
Yes	*No*	
3	10	<1%

Table 5.43 – Procurement concerns and initial construction cost increase of strategies that increase predictability in building systems

Cluster: Increase Predictability			
Initial design difficulty		Initial ease of construction	
Simple	*Difficult*	*Easy*	*Difficult*
12	1	13	0

Table 5.44 – Significant characteristics related to construction complexity of strategies that increase predictability in building systems

Accessibility for renovation construction is achieved by many of the strategies, but accessibility for operations and maintenance is achieved by a slightly smaller proportion of strategies in this cluster than in the whole sample (Table 5.45). Many of the strategies that improve predictability simply do so by indicating or maintaining constant locations of system components that are concealed behind or within others. Without removing the concealing component or system, accessibility cannot be improved.

Cluster: Increase Predictability					
Accessibility for operations and maintenance			Accessibility for renovation		
Improved	*No impact*	*Worsened*	*Improved*	*No impact*	*Worsened*
6	7	0	10	3	0

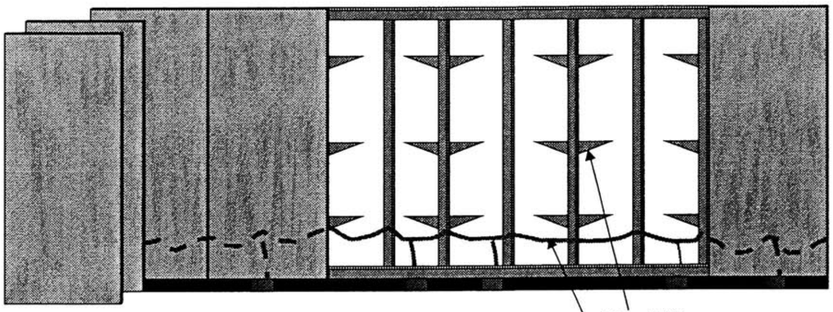
Table 5.45 – Significant characteristics related to accessibility for strategies that increase predictability in building systems

5.2.5.8 Cluster: Improve Physical Access

Since physical access to critical locations in a system is needed in order to implement a change, the provision of that access can reduce the complexity and duration of construction activities. The strategies in this cluster provide flexibility by improving access to particular systems. The example in Figure 5.24 shows an interior partition system with face panels that are easily removed and replaced, providing easy access to wiring distribution behind the panels.

Obviously, accessibility for either operations and maintenance or renovation should be improved by all the strategies in the cluster, which is shown in Table 5.46. Many strategies do have procurement concerns, yet the average initial construction cost is unexpectedly low (Table 5.47). Curiously, of the seventeen strategies with procurement concerns, the nine that do improve access have an average initial cost increase of only 1%, while the eight that do not improve access have an average increase of 5%. This indicates that, of building products that are available in the marketplace, those that seek to improve flexibility in physical access can often be inexpensive.

CLUSTER: IMPROVE
PHYSICAL ACCESS



Design Strategy:
Demountable, site-fixed,
finished drywall panels

Figure 5.24 – Example of a design strategy that achieves flexibility through improving access to critical building systems

Cluster: Improve Physical Access					
Accessibility for operations and maintenance			Accessibility for renovation		
Improved	*No impact*	*Worsened*	*Improved*	*No impact*	*Worsened*
13	0	0	13	0	0

Table 5.46 – Significant characteristics related to accessibility for strategies that improve physical access

Cluster: Improve Physical Access		
Initial construction procurement concerns		Percent increase in initial building cost
Yes	*No*	
9	4	1%

Table 5.47 – Procurement concerns and initial construction cost increase of strategies that improve physical access

Improved access is expected to lead to reductions in the downtime and higher savings when implementing changes. As expected, downtime involved in implementing a change is shortened in all the strategies in this cluster, and savings are relatively high (Table 5.48).

Cluster: Improve Physical Access			
Downtime resulting from implementing a change		Savings resulting from implementing a change	
Shortened	*No Impact*	*<$1/sf*	*>$1/sf*
13	0	3	10

Table 5.48 – Significant characteristics related to implementing changes when strategies are used to improve physical access

5.2.5.9 Cluster: Dedicate Volume for System Zoning

Rather than simply reduce spatial interactions by spacing systems far apart from one another, these strategies create volumes which house only a particular system. For example, Figure 5.25 shows a design in which the distribution of plumbing and wiring systems share a common volume inside a partition, and a design in which the wiring is instead routed through an architectural raceway at the partition's base. As a result of these segregated zones, making changes to either system is simplified in the latter design: changes can be made to one system without interference from others.

Construction of such volumes is expected to add significant cost and time to initial construction. Accessibility should be improved to these systems, for both renovation and operations and maintenance activities, which should lead to shortened downtime and high savings during implementation of changes.

The results are generally what are expected. The volume zoning reduces physical interactions and therefore shortens downtime. Accessibility is improved for most strategies (Table 5.49) as a result of the physical isolation of individual systems. When changes are implemented, downtime

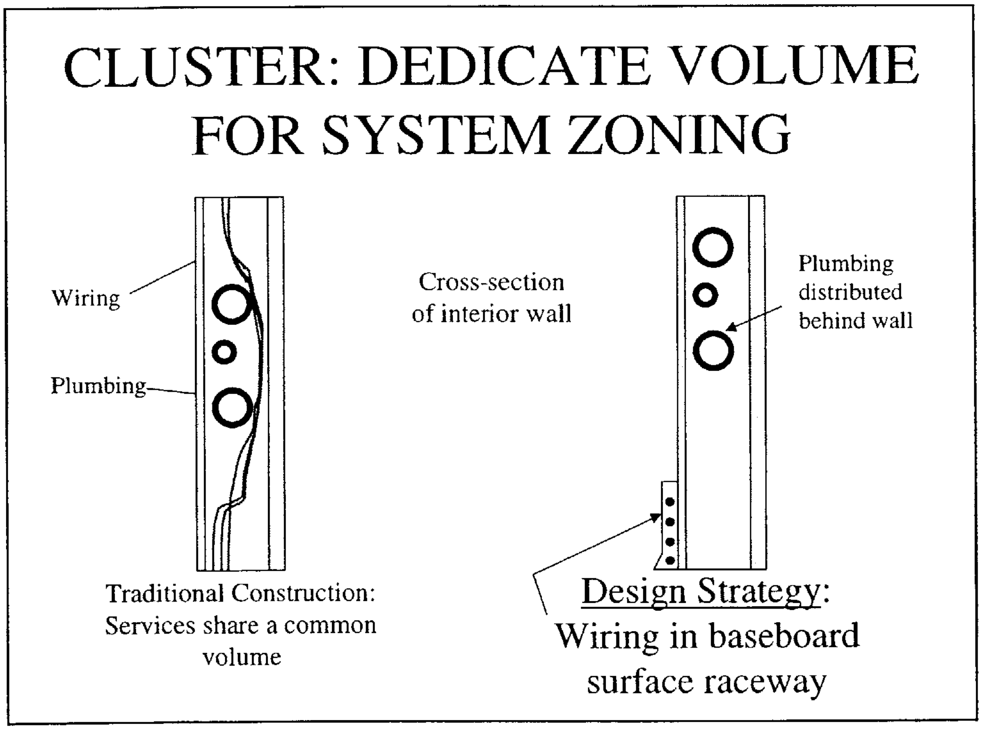


Figure 5.25 – Example of a design strategy that achieves flexibility through dedicating a volume for distribution of a specific system

is shortened in all of these strategies, and significant savings are realized in five of the 6 strategies in this cluster (Table 5.50).

Cluster: Dedicate Volume for System Zoning					
Accessibility for operations and maintenance			Accessibility for renovation		
Improved	*No impact*	*Worsened*	*Improved*	*No impact*	*Worsened*
5	1	0	5	1	0

Table 5.49 – Significant characteristics related to accessibility for strategies that dedicate space for specific systems

Cluster: Dedicate Volume for System Zoning			
Downtime resulting from implementing a change		Savings resulting from implementing a change	
Shortened	*No Impact*	*<$1/sf*	*>$1/sf*
6	0	1	5

Table 5.50 – Significant characteristics related to implementing changes of strategies that dedicate space for specific systems

Four of the six strategies identified make use of specialty components to create the dedicated volume (e.g., Multi-channel surface raceways, Overhead cable trays), all of which are used to isolate wiring from the structure and finish systems. The two that use conventional components and materials are both designs that create volumes beneath concrete slabs, providing a space for utility pipe distribution. Strategies of this nature have initial cost increases that are relatively low (Table 5.51).

Cluster: Dedicate Volume for System Zoning		
Initial construction procurement concerns		Percent increase in initial building cost
Yes	*No*	
4	2	1%

Table 5.51 – Procurement concerns and initial construction cost increase of strategies that dedicate space for specific systems

5.2.5.10 Cluster: Phase System Installation

The strategies in this cluster achieve flexibility by waiting to install a portion of a system until after initial construction. Provisions are made at initial construction to accommodate the particular system's growth. Only three strategies are included in this cluster, and all three are applied only to the structural system. Figure 5.26 shows how a structural system may accommodate additional stories or interstitial floors by strengthening the appropriate columns.

The increase in initial cost is expected to be very low, since phasing installation does not require significant material additions or additional construction activities during initial construction. Initial construction is expected to be shortened, because of the reduction in construction activity. Design and construction complexity are expected to be low.

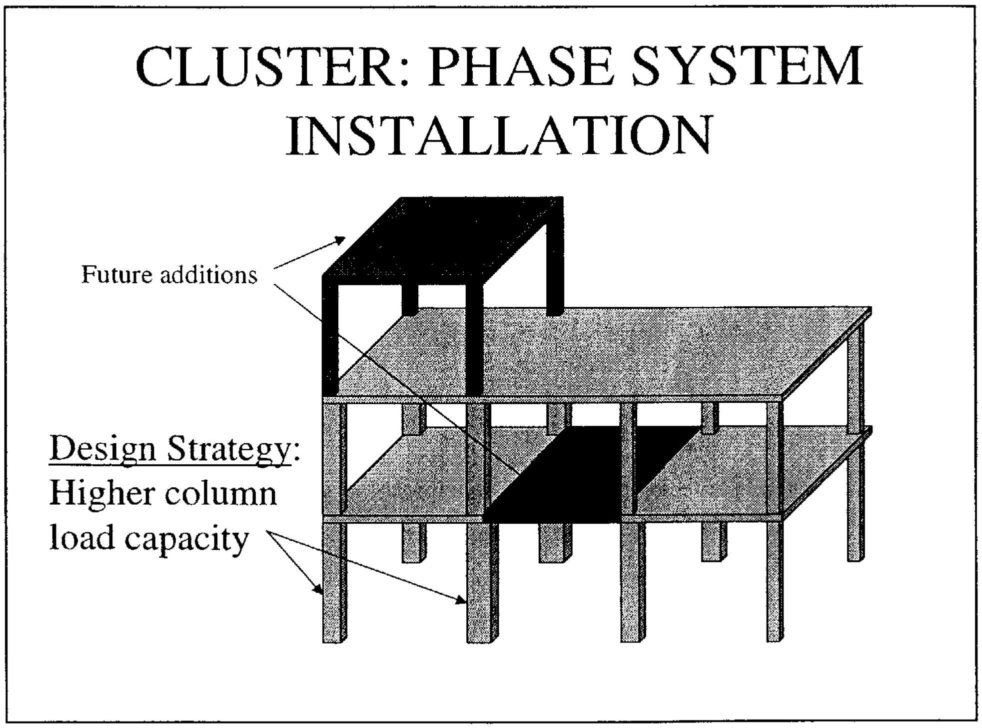


Figure 5.26 – Example of a design strategy that achieves flexibility through phased installation of a system

The three strategies all have simple design complexity, as expected (Table 5.52). One strategy (Interstitial mezzanine floor rack system) requires skills and familiarity with the system by the contractor. This strategy also has a shortened construction duration, resulting from reductions in material and construction activities. The other two strategies (Structural ladder system, structural column overcapacity) allow the easy addition of structural components to strengthen existing floors or create additional floors.

Cluster: Phase System Installation					
Design complexity		Construction complexity		Construction duration	
Simple	*Difficult*	*Easy*	*Difficult*	*No impact*	*Shortened*
3	0	2	1	2	1

Table 5.52 – Significant characteristics pertaining to initial construction for strategies that involve phased installation

Initial cost, as expected is quite low for the three strategies in this cluster. All three strategies are of very high value to systems requiring these specific changes, and the savings data resulting from implementing a change is the same for all three strategies: flexibility options presented by each design strategy are typically cost prohibitive to implement in buildings using conventional systems (Table 5.53). Again, this shows that many changes that would be too expensive to accommodate in the future can be cost-effectively managed during initial construction.

Cluster: Phase System Installation		
Savings resulting from implementing a change		Percent increase in initial building cost
Alternative is cost prohibitive	*Other*	
3	0	<1%

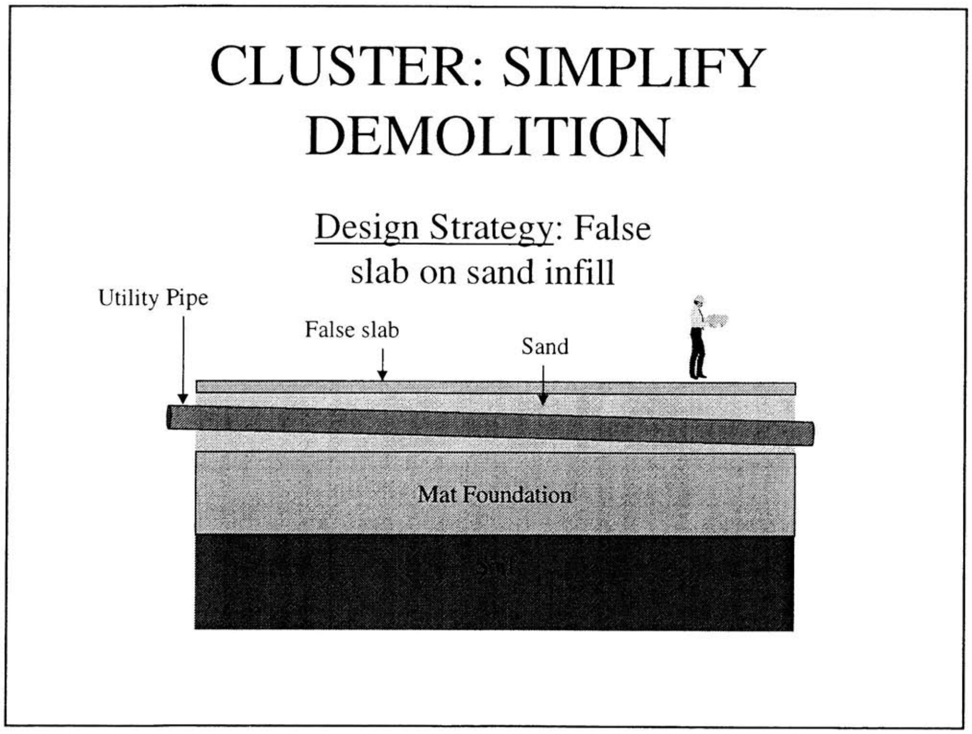
Table 5.53 – Savings from implementing a change and initial construction cost increase of strategies that involve phased installation

5.2.5.11 Cluster: Simplify Demolition

Two previous clusters have addressed the flexibility created by increasing the predictability of systems and improving access to systems in concealed locations. This cluster includes all strategies that simplify the demolition or disassembly activities of a building system, and is by far the largest cluster analyzed (20 strategies). Figure 5.27 shows a layer of sand sandwiched between a mat foundation and a thinner second slab. In this example, utility pipes are run in this sand layer, so that the pipes can be accessed without demolition of the mat foundation.

Several characteristics can be expected of strategies that are included in this cluster. The savings in cost for implementing a change are expected to be high, while the duration is expected to be shortened, due to the reduction of demolition activities and costs. Accessibility should be improved, since accessibility is often achieved by demolition of another system (e.g., demolition of drywall to access wiring or plumbing distribution behind a wall).

As expected, the downtime for implementing a change is reduced in 95% of the strategies, and significant cost reductions are found in 85% of the strategies in this cluster (Table 5.54).



CLUSTER: SIMPLIFY DEMOLITION

Design Strategy: False slab on sand infill

Figure 5.27 – Example of a design strategy that achieves flexibility through simplifying demolition activities

Cluster: Simplify Demolition			
Savings resulting from implementation of a change		Downtime resulting from implementing a change	
<$1/sf	*>$1/sf*	*No Impact*	*Shortened*
3	17	1	19

Table 5.54 – Significant characteristics related to implementing changes when strategies are used to simplify demolition activities

Accessibility for renovation is improved in 70% of strategies (Table 5.55), which is proportional to the amount of strategies that achieve this in the entire sample. Accessibility for operations and maintenance is improved in 13 (65%) of the strategies in this cluster, which is significant, since only 18 strategies in the whole sample (49%) improve this type of accessibility. The one strategy in the sample that worsens access (office pods) is included in this cluster. Since improvement of operations and maintenance activities are rarely the goal of design strategies, this implies that the accessibility for operations and maintenance is a common secondary benefit of design strategies that improve demolition.

Cluster: Simplify Demolition					
Accessibility for operations and maintenance				Accessibility for renovation	
Improved	*No impact*	*Worsened*	*Not applicable*	*Improved*	*No change*
13	3	1	3	14	6

Table 5.55 – Significant characteristics related to accessibility of systems for strategies that simplify demolition activities

Many strategies have procurement concerns, indicating a high reliance on specialty building products to improve demolition ease. The initial increase in construction costs is slightly higher than the average of the entire sample (Table 5.56). There are a surprisingly large number of strategies that simplify demolition without lengthening the initial construction process, and indeed, two strategies also shorten initial construction.

Cluster: Simplify Demolition					
Initial construction Duration			Initial construction procurement concerns		Percent increase in initial building cost
Lengthened	*No Impact*	*Shortened*	*Yes*	*No*	
6	12	2	14	6	2%

Table 5.56 – Significant characteristics related to initial construction of strategies that simplify demolition activities

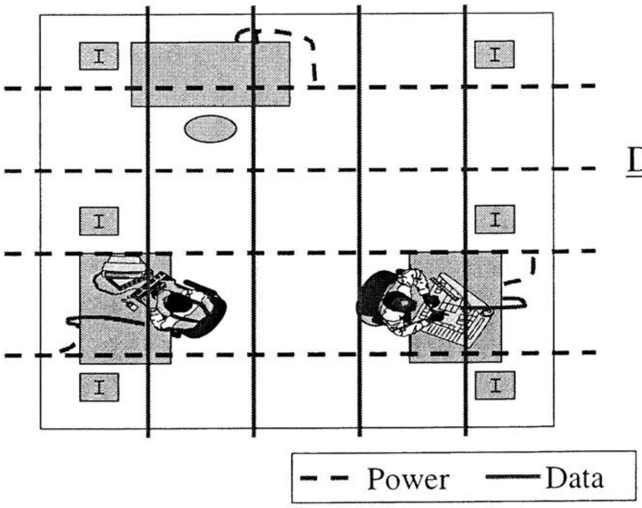
5.2.5.12 Cluster: Enhance System Proximity

The twelve strategies in this cluster enhance flexibility by shortening the distance from critical locations in the system to the location of the users who require access to the system. For example, an overhead (or under-the-floor) grid-style layout of power and data distribution provides close proximity to all locations throughout an open building plan (Figure 5.28). New terminals may be added without redistributing service to the terminal location each time.

Few procurement concerns or initial cost increases are expected, since the provision of enhanced proximity can be achieved simply through new layout or configuration of one or more systems. These strategies would likely need to improve accessibility for operations and maintenance, and for renovation, since close proximity to certain systems can only be a benefit if the systems are also accessible.

Most of these strategies can be implemented with conventional materials at a lower than average cost (Table 5.57). Accessibility is improved in 75% of the strategies for operations and maintenance, as well as for renovations (Table 5.58).

CLUSTER: ENHANCE SYSTEM PROXIMITY



Design Strategy:
Floor plan
wiring grid

Figure 5.28 – Example of a design strategy that achieves flexibility through enhancing the proximity of a building system to the building users' connections

Cluster: Enhance System Proximity		
Initial construction procurement concerns		Percent increase in initial building cost
Yes	*No*	
3	9	1%

Table 5.57 – Procurement concerns and initial construction cost increase of strategies that enhance the proximity of systems to users

Cluster: Enhance System Proximity					
Accessibility for operations and maintenance				Accessibility for renovation	
Improved	*No impact*	*Worsened*	*Not applicable*	*Improved*	*No change*
9	2	0	1	9	3

Table 5.58 – Significant characteristics related to accessibility of systems for strategies that enhance the proximity of systems to users

It is also expected that strategies in this cluster should reduce the necessary downtime and increase savings resulting from implementing a change, which is found to be true for most strategies (Table 5.59).

Cluster: Enhance System Proximity				
Downtime resulting from change implementation			Savings resulting from change implementation	
Shortened	*No impact*	*Lengthened*	*<$1/sf*	*>$1/sf*
9	3	0	4	8

Table 5.59 – Significant characteristics related to change implementation for strategies that enhance the proximity of systems to users

5.2.5.13 Cluster: Improve Flow through System Layout

Strategies in this cluster provide flexibility by strategically locating major building components (such as utility cores, stairwells, and risers) in the layout of the building in a way that accommodates changes in flow through the building. Figure 5.29 illustrates two options for locating the cores in a building.

Strategies in this cluster are expected to have low levels of complexity in design and construction, as well as low initial costs and few procurement concerns, since the designs can be achieved simply by rearranging conventional components in the building systems. Since the layout affects many building system designs, it is expected that projects will have high levels of commitment to these strategies.

Of the five strategies in this cluster, one is applied to the services, three to both the structure and service systems, and one to the finish system. All five have identical characteristics (Table 5.60) in level of commitment (*total commitment*), use of unconventional building materials and components (*no procurement concerns*), and increase in initial building cost (*Variable about zero*). The cost and savings impacts on the construction systems, with respect to another

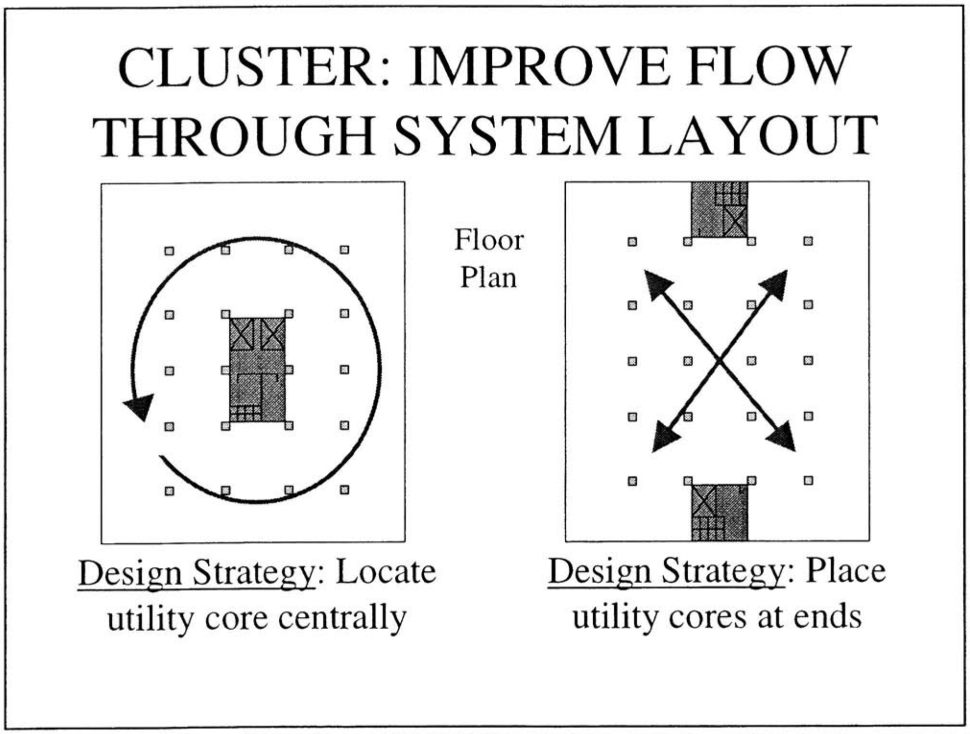


Figure 5.29 – Examples of design strategies that achieve flexibility through improvements in layout

conventional alternative, are very difficult to estimate due to the complexity of systems involved (i.e., relocating the utility core has impacts on all the service subsystems that are distributed through the core). Simplicity of design and construction is shown in Table 5.61.

Cluster: Improve Flow through System Layout				
Irrevocability of commitment		Initial construction procurement concerns		Percent increase in initial building cost
Total	*Other*	*Yes*	*No*	
5	0	0	5	*Variable about zero*

Table 5.60 – Level of commitment, procurement concerns, and initial construction cost increase of strategies that achieve flexibility through the layout of building systems

Cluster: Improve Flow through System Layout			
Initial design difficulty		Initial ease of construction	
Simple	*Difficult*	*Easy*	*Difficult*
5	0	5	0

Table 5.61 – Significant characteristics related to construction complexity of strategies that achieve flexibility through the layout of building systems

5.3 Selecting Appropriate Design Strategies

For the user types examined in this research where at least two facilities were examined, the needs of typical users are matched to the most appropriate design strategies for their expected projects. In each section, the buildings examined in the particular user type category are listed with the associated design strategies used at their projects. For each user type, a set of strategies is then recommended that is expected to create a high level of flexibility in the typical user's building, for which the costs, benefits, and special considerations are discussed. Three particular buildings are also examined as case studies, and additional or different design strategies than the ones actually selected are recommended for each.

The strategies were selected by following the four-step analysis process described in Section 3.2. Effective strategies were first identified by matching the matrices used to classify user needs and strategy achievements. Complementary strategies were identified by first finding strategies that achieve some or most of the facilities needs for flexibility, then recognizing the remaining unsatisfied needs, and finally finding strategies that could fulfill these remaining needs. The costs and benefits of satisfactory strategies were examined, and the most valuable strategies were selected.

The use of the matrices to identify complementary strategies was found to be very successful at eliminating many strategies that would not complement one another, but not as successful at determining the *best* complementary strategies, because of the way that expected changes and achievements are classified. For example, the following three strategies are all good at aiding in the rearrangement of telecommunications functions: raised access floors, overhead cable trays, and modular wiring systems. All three have X's in the *New Function – Telecommunications* intersection of their corresponding achievement matrices. The access floors and modular wiring systems complement one another, since the modular wiring allows the wiring connections to be altered, and the floor provides a space for distribution and a means for accessing the modular wiring systems. The overhead cable trays could complement the modular wiring in the same way. However, the access floors and overhead cable trays are *not* complementary, but redundant, since they perform identical functions (i.e., improve access and provide a dedicated distribution volume). Therefore, after most strategies that could not possibly complement one another were eliminated by matching matrices, the actual functions performed by the remaining strategies were examined to identify strategies that are truly complementary.

5.3.1 Research and Development Facilities

The four research and development facilities examined in this research are listed in Table 5.62, along with the design strategies that are used at these projects.

R&D facilities examined	Design strategies used at these facilities
270 Albany Street Aberdeen Proving Ground Building 314 Unilever Research	Multi-channel surface raceways Two-end core layout Raised floor systems Demountable mid-height partitions Demountable full-height partitions Utility risers at columns Room size standardization Exposed ceilings with overhead distribution Street layout Small-area VAV units Task lighting High density of vertical shafts

Table 5.62 – Research and development projects examined and design strategies used at these facilities

Generally, the primary need for flexibility at research and development laboratories comes from reorganizing research facilities to accommodate new projects. To provide a high level of flexibility in these facilities, the following design strategies are recommended for concurrent use:

1. Exposed ceilings with overhead distribution – For general R&D labs, exposed ceilings with overhead distribution works quite well for providing services to all areas of a floor, as well as incorporating new service distribution easily.

2. Demountable full-height partition systems – These partitions can be used to subdivide space while providing privacy for working.

3. Overhead drainage system – This strategy, which allows wet tables in laboratories to be relocated without demolishing the floor, was not used at any of the facilities examined. Because of the relative difficulty of rearranging pipes (as compared to rearranging cabling), this need is often quite difficult to accommodate, but the overhead system drastically reduces the difficulties associated with implementing these changes. However, there may be a certain amount of risk when this system is used in an environment where employees may be disposing of caustic or potentially hazardous materials, which may erode components in these systems. Other design strategy alternatives exist for drainage flexibility (e.g., false slab,

interstitial space beneath a structural slab), but are most applicable to drainage at the ground-floor, and more appropriate for infrequent changes.

One alternative to the overhead drainage system would be an access floor, beneath which the drainage pipes could be routed. This access floor would have to be very deep, to accommodate the necessary slope of the pipes, and is likely to be more expensive to install than the overhead system, unless the laboratory is very small. Mechanical pumps beneath such a floor may allow a shallower drainage slope, but would require a larger initial construction investment, and would create increased operations and maintenance activity.

Another possible alternative strategy would be to increase the number of vertical distribution shafts, which would provide many options for locating drains adjacent to shafts. There is a very high level of commitment to this strategy, however, and the many shafts disrupt the flexible space, restricting the options for subdividing the space.

5.3.2 Office Buildings

The nine buildings with office space that were examined are listed in Table 5.63, with the design strategies used at these projects.

Office buildings examined	Design strategies used at these buildings
9/90 Corporate Center	Multi-channel surface raceways
Gap, Inc.	Two-end core layout
K. Wayne Smith Building	Demountable mid-height partitions
Metro-Dade Center	Raised floor systems
Owens Corning Headquarters	Office pods
Revenue Canada Building	Accessible modular wiring
Building 314	Poke-through floors
Unilever Research	Access floor delivery system
Igus Factory	Access floors housing mechanical ducts
	Task lighting

Table 5.63 – Projects with office space examined and design strategies used in these buildings

For typical offices, the main type of flexibility to be accommodated is a high level of churn. The following set of design strategies provides a high level of flexibility at a reasonable cost.

1. Access floor delivery system – Raised access floors were used in four of the offices, and are very good for distributing new services and redistributing existing services when rearrangement of the office layout happens. By using the plenum beneath the floor to

distribute and rearrange ventilation, a level of flexibility is attained that would normally be cost prohibitive. These systems are also quite affordable, since the reduction or elimination of HVAC supply ductwork offsets the initial cost increase of the access floors and vents.

2. Modular wiring – This design strategy shortens the downtime from making changes in wiring distribution and its use is complemented by the accessibility provided by raised access floors. There is some risk involved in using these systems, associated with the solvency of the product's manufacturer (i.e., if the manufacturer goes out of business, replacement components may not be available).

3. Two-end core layout – Locating the service cores at the building perimeter creates less interruption of the working area than locating the cores at the center (i.e., large open square, rather than a donut-shaped plan). This is especially effective in offices with smaller building plans.

Office pods are highly flexible, and a very effective means of segregating office space from other usage areas, but because of the high cost, should only be used where office space must be isolated and frequently moved. Also, the pods are difficult to relocate in areas where there are obstructions such as structural columns, so column-free zones are needed, which can also be very costly to create.

5.3.2.1 Case Study: Metro-Dade Center (Miami, Florida)

The Metro-Dade Center is a slender, 31-story office structure in Miami, Florida, which regularly experiences rearrangement changes. To accommodate these changes, the facility uses poke-through floors, which allow wiring to be distributed to any location on the floor, by coring holes through the slab and accessing wires in cable trays hung beneath each floor. This strategy does not seem to be as effective as some alternative strategies at fulfilling the goals set forth by the owner. Access floors can better accommodate these frequent changes, since disruption is limited (i.e., no interruption of operations on the floor below), and new service functions are more easily distributed. Another option might be to use overhead cable trays, but space at the Metro-Dade Center is subdivided by mid-height partitions, limiting locations where services may be "dropped down" from overhead.

Because of the building's tall height and fairly small floor area, two additional strategies are recommended. First, isolating service cores at the two building ends maximizes the uninterrupted space, making it more functional. Second, using oversized vertical shafts allows for new services to be distributed to all floors of the building, which is important, given the large size of vertical distribution mains that may be necessary for supplying service to as many as 31 floors.

5.3.3 Office/Manufacturing Mixed-Use Facilities

Two buildings examined combined office space with manufacturing (Table 5.64). Because of their ever-changing manufacturing needs, these mixed-use buildings require strategies that allow them to change not only the location of office areas, but also the relative proportions of office and manufacturing space. There are two basic, yet very different means of segregating these areas within a facility: partition a common space to divide the two usage areas, or create small areas for one usage that essentially "float" within the larger space for the other usage. These two options are examined in the following case studies.

Office/Manufacturing facilities examined	Design strategies used at these facilities
Igus Factory	Column-free zones in structure
Abbott Laboratories	Office pods
	Modular panel cladding
	Demountable full-height partitions
	Demountable mid-height partitions
	Raised floor systems
	Two-end core layout
	Utility risers at columns
	Small-area VAV units
	Task lighting

Table 5.64 – Projects examined that have common office and manufacturing spaces, and design strategies used at these facilities

5.3.3.1 Case Study: Igus Factory (Cologne, Germany)

The Igus Factory is a large, single-story facility for creating injection-molded plastics, which contains a large amount of flexible manufacturing area and several small office pods. Slender steel tension members extend from tall masts that rise above the structure to support the facility's roof, eliminating columns in the manufacturing area. Office pods can be built virtually anywhere in the manufacturing area, creating a set of small modules that can be disassembled and reassembled with little or no waste as processes and layouts change. Both of these strategies are very expensive during initial construction, but Igus feels they are necessary for being able to respond quickly to changes in processes, and to their clients' new injection-molded plastic needs. The Igus Factory also uses a modular panel cladding system that allows easy changes in the flow of materials into and out of the facility, and maximizes enclosure material reuse when the existing facilities are expanded.

Igus has made a large commitment to incorporating strategies that will aid in its facility's flexibility, so few needs have gone unmet. One additional strategy, the use of overhead drainage systems, is recommended, since it allows drainage to be reconfigured within the space, which is expected to occur when processes change at the factory.

5.3.3.2 Case Study: Abbott Laboratories (Las Colinas, Texas)

This four-story facility has a warehouse on the ground floor and manufacturing and office space on the upper three floors, which is constructed as a common space that uses demountable full-height partitions to segregate the usage areas. These partitions are frequently moved as the shape of the manufacturing space is required to change to accommodate new processes. For this reason, the utilities are essentially standardized throughout the space: at each column are connections to electrical and plumbing services, for which a raised floor is used to provide access. Cores are placed at each end of the building to keep the space as uninterrupted and flexible to configuration changes as possible. Within each bay are two zones for temperature control and various task lights, reducing the partitions' interference with the flow of air provided by the HVAC systems and illumination from the overhead lighting grid.

To aid changes in ventilation, an access floor delivery system would work well for this facility, especially since the access floor is already in place. There may be some problems with this system, however, due to the large amount of electrical and plumbing distribution under the floor, which could impede proper air flow in the plenum.

The modular panel cladding system that works quite well for Igus is could be very helpful in changing flows of material and products in and out of the manufacturing space. However, since Abbott's manufacturing facilities are not on the first floor, materials and products must flow through freight elevators at either end of the building. Therefore, this strategy is not expected to be useful here, because the location the freight elevators will be stationary.

5.3.4 Residential Buildings

Two residential buildings were examined in this research, and both used the same design strategy: extra vacant conduits were installed during initial construction, originating at a single point in the building and terminating in each residential unit (Table 5.65). This strategy is used to allow cabling for new services to be added with minimal demolition of finish systems. Two additional design strategies are recommended for use in these buildings.

Residential buildings examined	Design strategies used at these buildings
Boston University Dormitory Summit Properties Apartments	Extra vacant conduit

Table 5.65 – Residential buildings examined, and the single design strategy used in these buildings

1. Street layout – Residential buildings usually have a large amount of hard-finish space, and residential units typically follow the same layout on each floor. For this reason, services are often distributed vertically through a certain location in each "stack" of units (e.g., a utility closed near the kitchen and bathroom of each floor). The problem with this design is that all maintenance activities must occur inside the residential units. Alternatively, if the utilities are located in the corridors of the buildings, many maintenance activities can be performed outside the units. For the same reason, the distribution of new functions becomes easier.

2. Site-fixed panel partitions – These systems are good for residential units, since walls are not expected to move and access to space behind the wall is desired for incorporating new functions, such as service for internet access, satellite or cable television, and other information technology. Panels have a fabric finish that is more durable than painted drywall, and the replacement of damaged panels is quite easy.

5.3.5 Educational Facilities

The four educational buildings examined are listed in Table 5.66, with the strategies that were used at these facilities.

Educational facilities examined	Design strategies used at these buildings
Building 16, MIT Mashpee Jr./Sr. High School	Exposed ceilings with overhead distribution Extra fiberoptic lines Street layout High density of electrical outlets Raised floor Access floor delivery system Small area VAV units

Table 5.66 – Educational facilities examined, and design strategies used at these buildings

Schools typically have finish systems that are "hard," or fixed in place, rather than dynamic, or "soft." School buildings are often constructed provide adequate flow of people to their destinations, following a layout that can be likened to a street: students travel through a system of corridors, then exit when they come to their destination, which is located right off the corridor. Because of the large reach of these corridors, students rely on familiarity with the "streets" to navigate themselves to their proper destination. Rearranging these streets leads to confusion and requires maps and signage that would have to be updated constantly. Also, since schools are often quite large, there may be a variety of room sizes and functions available, so that when a space is not sufficient for a certain task, the users may be relocated to an existing room, eliminating the need for rearranging partitions. Because of hard-finished corridors, the street layout design strategy provides an adequate means of distributing new and existing services to classrooms, and demountable partitions are not expected to be useful, and therefore not recommended.

In a break from traditional educational construction, some facilities, such as the new Stata Complex at the Massachusetts Institute of Technology, are incorporating open-plan space in their buildings. These large areas may be subdivided to create many classroom or laboratory areas, and may change in layout and function of space as often as two or three time a year, with each new class term. In these buildings, the needs of the educational user resemble the needs of office users, which are dominated by changes in layout. The street layout is not recommended for these buildings, since the location of the "streets" will be constantly changing. Instead, as in offices, access floor delivery systems, modular wiring, and demountable partitions together create the most appropriate flexibility.

5.3.6 In-Patient Medical Facilities

Table 5.67 shows the two hospitals that were examined, and the design strategies that were used by them. These strategies provide additional capacity for new loads on the systems, especially those needs associated with volumetric growth of the facility, either horizontally or vertically. The costs are generally very low, and are very effective when the needs can be predicted very specifically.

In-patient medical facilities examined	Design strategies used at these buildings
Mount Auburn Hospital	Structural column overcapacity
San Joaquin General Hospital	Enhanced performance cabling systems

Table 5.67 – In-patient medical facilities examined, and the design strategies used in these buildings

Four additional strategies are recommended for typical in-patient medical facilities.

1. Street layout – Hospitals, like conventional school buildings, are designed to offer the best flow of people through the facilities. Corridors are hard-finished, and running utility mains along the corridors provides close access for new service loads in each room, and also allows operations and maintenance activities and the installation of new services to be performed without interrupting patients in rooms.

2. Room size standardization – This allows rooms to be joined to create larger space, when needed. This might be most effective if demountable full-height partitions can be used, which would only be possible where patient monitoring equipment does not need to be mounted to walls.

3. Overhead cable trays – This strategy is excellent for flexible distribution inside rooms off the corridors, since it allows for connections to monitoring systems and other medical support equipment that can be expected to vary with each patient. When not needed, wires can be easily stored and concealed.

4. High density of electrical outlets – Because the amount and type of medical support and monitoring equipment varies with each patient, a high density of electrical outlets will be required, so that power connections are never in short supply.

5.4 Summary

Application of the framework provides new insights into the nature of changes needed in different types of facilities, and the variety and applicability of means to achieve those changes. While no particular design strategy is perfect for all facilities and owners, there are many different strategies that may be used. The benefits and applicability of these design strategies may vary with a building's usage class and physical characteristics. A building designer or facility manager could use this framework to properly select one or more design strategies that would satisfy the needs set forth by an owner for a particular project.

6 Conclusions and Recommendations for Further Research

6.1 Summary

The objective of this research was to identify and analyze the approaches and strategies involved in the design and construction of built facilities that explicitly take into account changing needs over a given facility's life. A framework for evaluating design strategy alternatives for a given project was successfully developed. This framework consists of a four-step process that thoroughly examines several critical characteristics of each strategy, generating the results of the strategy analyses. Approaches were analyzed by examining trends in the characteristics and results of analyses of strategies in the appropriate clusters or approach categories.

6.2 Conclusions

6.2.1 Conclusions about the Analytical Process

Change type categories were found to sufficiently categorize all changes encountered, such that all changes identified could be classified as one of these types. Likewise, the building subsystems used for classifying user needs and strategy achievements adequately described all the systems and subsystems of buildings, such that no changes or design strategies were applied to subsystems other than these. User needs and design strategy achievements might also be classified consistently using different sets of change types and building systems, subsystems, or components, as desired by the owner, occupant, or designer. However, these change types and building systems must be clearly identified early in the process, so that each design strategy can be evaluated in the same way. Later changes to the change type or system categories may require reevaluation of all strategies.

The use of the matrices to identify complementary strategies is very good for identifying strategies that help achieve the goals set forth by the user, as well as eliminating strategies that would not complement one another. The method is not as successful at determining the *best* complementary strategies, because of the way that expected changes and achievements are classified. For example, the following three strategies are all good at aiding in the rearrangement of telecommunications functions: raised access floors, overhead cable trays, and modular wiring systems. All three have X's in the *New Function – Telecommunications* intersection of their corresponding achievement matrices. The access floors and modular wiring systems complement one another, since the modular wiring allows the wiring connections to be altered, and the floor provides a space for distribution and a means for accessing the modular wiring systems. The overhead cable trays could complement the modular wiring in the same way. However, the access floors and overhead cable trays are *not* complementary, but redundant, since they perform identical functions (i.e., improve access and provide a dedicated distribution volume). Therefore, after eliminating most strategies that could not possibly complement one another by matching matrices, the particular functions performed by the remaining strategies must be further examined to identify strategies that are truly complementary.

Analyzing the data at the design strategy level is a more effective means of identifying relationships among characteristics than analyzing the data at the approach/clustered means level. Analysis at the clustered level allows certain expectations about the characteristics of design strategies in that cluster to be confirmed or refuted. Because no mutually exclusive clusters or approaches were identified among the 37 strategies however, the effectiveness of one general means of achieving flexibility could not be compared to another (i.e., one or more strategies could follow both general means of achieving flexibility).

6.2.2 Conclusions about User Needs

Some buildings expect to encounter most changes in the short term, within five years after completion of initial construction. Those buildings are typically office buildings, manufacturing facilities, and educational buildings. Other projects, like laboratories, residences, medical facilities, and retail stores, expect most changes to be encountered in the medium term (i.e., more than five years and fewer than fifteen years after initial construction). Few projects expect most changes to occur more than fifteen years after initial construction and not before that time.

Nearly all users expect to encounter upgrades of functions, incorporation of new functions, and changes in the flow of people and things. These change types are fairly common changes that are frequently encountered in the short-term, often shortly after initial construction is complete. The more distant the expected change, the better chance that something might happen to make the change unlikely to occur. Hence, investment in accommodating long-term changes could be viewed as a risky action, paying to allow benefits that might not be reaped. Users tend to have a clearer view of needs that will occur in the short term, and appear to be more comfortable planning for these needs. Very few users expect their buildings to experience a modification for new usage class, a change that might typically be expected to occur only in the distant future. In fact, few users expect their buildings to accommodate new users, even in the same usage class. Owners may feel that the benefits of flexibility cannot increase the market value of their building and allow owners to recover their additional investments into flexible designs if the building is sold.

6.2.3 Conclusions about Design Strategies

Many design strategies have benefits that are unintended, underutilized, or not needed by their users. Many selected strategies may offer more flexibility than owners or occupants need, or may even realize exists. This is reflected in the relatively high number of strategies that increase the capacity of a building to be modified for a new usage class, even though very few users expect to require such a change.

Significant flexibility can be achieved as a result of interactions between systems. Reducing interactions between systems, especially reducing the physical and spatial interactions between the finish and service systems, is a common means of creating flexibility in one system by altering the design of another. These interactions also sometimes impose restrictions on the use of certain design strategies, which may only be applicable or technically feasible when, say, certain other systems are a particular size or shape, or made of a specific building material. Most frequently, it is the structural system that imposes these restrictions on a strategy's use, regardless of the system to which the design strategy is applied.

The cost of implementing a design strategy during initial construction typically increases the overall building cost by only a very small amount – usually less than two or three percent. Some strategies have higher cost increases though, typically resulting from the use of unconventional building materials or specialty products that are expensive or difficult to procure. Strategies are not likely to be implemented for the purposes of improving operations and maintenance activities or costs. Any costs or benefits for operations and maintenance are typically viewed as secondary impacts. Most design strategies require at least a significant level of commitment, such that in the event of strategy failure, there will be major costs associated with replacing the failed design with a new one.

Given the benefits that can be achieved with flexible designs, the cost of incorporating a design strategy for accommodating these changes is surprisingly low. Savings resulting from the use of design strategies vary over a large range, with most benefit-to-cost ratios (BCR) less than 1 or 2, but some have a BCR higher than 10! Many design strategies enable changes that would be cost prohibitive when using conventional design alternatives. Also, most design strategies shorten the downtime resulting from change implementation, regardless of whether or not they impacted the initial construction duration.

6.3 Recommendations for Further Research

Estimating the costs of design strategies was often difficult, and highly dependent on characteristics of a particular building's design. Furthermore, since many strategies enabled changes that are typically cost prohibitive when using conventional designs, little documentation of the costs of these changes was available. The development of software programs that can estimate these costs at the task-level for a number of strategies and many specific designs, taking into account interactions among and between systems, would be very valuable to the research, greatly improving the accuracy of cost estimating.

One design strategy characteristic that could be further explored is the level of risk associated with a particular strategy's use. This would likely involve examination of ways to determine whether or not a design strategy has failed to accomplish its intended goals, factors that influence the success or failure of a design strategy, the probability of a given design strategy's failure, and the costs associated with remedying failure of a design strategy.

Finally, further research into the transferability of the benefits from facilities with a high capacity to accommodate change could provide answers about the wisdom of investing in these strategies. Research could focus on determining whether the benefits of flexibility are transferable from the owner to the occupants, in such a way that the cost of adding value to a given space could be recovered by the owner in the form of higher tenant rents, or whether the benefits of flexibility increase the market value of a building, such that an owner could reclaim the investment made during initial construction when the building is sold.

APPENDIX A

Descriptions of projects examined in this research, and user needs matrices for each project.

List of Project Descriptions and User Needs Matrices

ABBOTT LABORATORIES (LAS COLINAS, TEXAS)

Abbott Laboratories is a developer and manufacturer of health care products and services, including pharmaceutical, laboratory, and hospital products. Their four-story Las Colinas facility is the home of Abbott's Diagnostics Division, which manufactures medical diagnostic equipment and is Abbott's primary instrument manufacturing location. The facility was designed (for first construction) with the intention that a given space could be interchanged from office to manufacturing and back again "in a heartbeat."

A large, open area is created in the center of the building by relegating elevators, rest rooms, electrical and mechanical closets, private office space, and other "hard" facilities to the building's two ends. Water/drainage and electricity are distributed vertically through the building at multiple columns, in the immediate vicinity of equipment placed anywhere on the floor. The raised floor provides access to horizontal distribution of power and plumbing. Air distribution is controlled at many small-area, variable-air-volume (VAV) units (spaced at two VAV units per bay), allowing users to regulate the temperature at each location. Full-height demountable partition walls are used to separate the office areas from the manufacturing space, and mid-height demountable partitions separate individual office spaces.

Design Strategies used at Abbott Laboratories
1. Two-end core layout
2. Raised flooring
3. Demountable mid-height partitions
4. Demountable full-height partition walls
5. Utility risers at columns
6. Small-area VAV units
7. Task lighting system

Table A.1 – Design strategies used at Abbott Laboratories

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw												▨	▨								
	Md						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T	▨	▨								▨		▨	▨	▨					▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T	▨	▨					▨			▨		▨	▨	▨					▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨							▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T	▨	▨					▨			▨		▨	▨	▨					▨	▨	

User needs for
Abbott Labs

ABERDEEN PROVING GROUND (ABERDEEN, MARYLAND)

This U.S. Army research facility incorporates rooms ranging in size from 80-sf to 7,000-sf, and in purpose from administrative offices to clean rooms to explosion-proof material testing areas. This diversity of research projects requires that firewalls to be constructed throughout much of the building, and other finish systems that are not movable or flexible.

Uses a street layout so that changes or additions to laboratory configurations can occur with relative ease by simply attaching to main runs in the facility's corridors.

Design Strategies used at Aberdeen Proving Ground
1. Street layout

Table A.2 – Design strategies used at Aberdeen Proving Ground

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up													▨								
	Nw												▨	▨								
	Md																					
Capacity	Ld							▨			▨			▨	▨							
	Vm																					
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨					▨	▨	▨	▨
	Nw							▨					▨	▨					▨	▨	▨	▨
	Md																					
Capacity	Ld							▨			▨			▨	▨							
	Vm																					
Flow	Env																					
	P/T							▨			▨		▨	▨	▨					▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨							▨	▨					▨	▨	▨	▨
	Nw							▨					▨	▨					▨	▨	▨	▨
	Md																					
Capacity	Ld							▨			▨			▨	▨							
	Vm																					
Flow	Env																					
	P/T							▨			▨		▨	▨	▨					▨	▨	

User needs for Aberdeen Proving Ground

270 ALBANY STREET (CAMBRIDGE, MASSACHUSETTS)

Originally built in 1920, this facility served as a light manufacturing plant until it was closed in 1990. In 1998, Lyme Properties of New Hampshire purchased the building and it was renovated to become office and R&D space. The building has two stories and a full basement, with floor-to-ceiling heights of 9-, 15- and 10-ft (basement to second floor). These heights, coupled with the structural capacity of the building, allow it to accommodate many building usage classes. The developer also recognized that the building was large enough to accommodate multiple tenants, if properly fit-out.

Multiple vertical shafts were used for service distribution, chiefly for the purpose of reducing the length (and therefore, depth) of horizontal distribution. This increased density of shafts, however, also allows for more flexibility in changes. Services were distributed overhead horizontally in ducts and a cable tray management system built using Unistrut brand components. The ceiling was left exposed, providing access to services for changing layouts within rooms.

Design Strategies used at 270 Albany Street
1. Exposed ceilings with overhead distribution
2. High density of vertical shafts

Table A.3 – Design strategies used at 270 Albany Street

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw												▨	▨								
	Md																					
Capacity	Ld							▨		▨	▨	▨	▨		▨							
	Vm																					
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md																					
Capacity	Ld						▨	▨	▨	▨	▨	▨	▨		▨							
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨	▨					▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨							▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md																					
Capacity	Ld						▨	▨	▨	▨	▨	▨	▨		▨							
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨	▨					▨	▨	

User needs for
270 Albany St.

BOSTON UNIVERSITY DORM (BOSTON, MASSACHUSETTS)

This large dormitory on the BU campus is currently under construction and should be completed in time for the 2000-01 academic year. The dorm is approximately 200,000-sf and consists of three towers (18-, 15-, and 9-stories) of dormitory "suites." Each suite has two or four single bedrooms, two bathrooms, some kitchen facilities, and a common area.

Boston University recognizes the changing computer and communications needs for students in dormitories, and provides full internet access to each suite. To accommodate future, unknowable advances in computer technology, the university installs a system of vacant ¾"-conduit to each room, originating at a single location in the building. This allows the simplest means of providing later service without having to demolish interior finish. By installing this conduit during the building's initial construction, the cost is only a negligible increase.

Design Strategies used at Boston University Dorm
1. Extra vacant conduit

Table A.4 – Design strategies used at Boston University Dorm

Needs Framework

		Short-term needs (1-5 years)																						
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm									▨	▨	▨	▨	▨								
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																						
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																		▨	▨		
	Nw											▨	▨									
	Md																					
Capacity	Ld																					
	Vm									▨	▨	▨	▨	▨								
Flow	Env																					
	P/T						▨	▨	▨	▨	▨				▨	▨				▨	▨	

		Long-term needs (15-30 years)																						
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨								▨					▨	▨	▨	▨
	Nw											▨	▨									
	Md																					
Capacity	Ld																					
	Vm									▨	▨	▨	▨	▨								
Flow	Env																					
	P/T						▨	▨	▨	▨	▨				▨	▨				▨	▨	

User needs for
Boston University Dorm

BUILDING 16, MASSACHUSETTS INSTITUTE OF TECHNOLOGY (CAMBRIDGE, MA)

Building 16 houses classrooms, offices, and laboratories for organic chemistry and biochemistry on the MIT campus. By 1994, the wet labs built during original construction had become obsolete, and new labs were required. A renovated facility was designed with the goal of incorporating flexibility in space and services that would accommodate user needs for 25-30 years, with no renovations expected in the 8-10 years immediately following construction.

Services in Building 16 are distributed horizontally through the corridors of the building (commonly called a "street layout" or "racetrack"), so additional lines to rooms can be easily attached to the mains. These services are distributed throughout the rooms using an overhead cable-tray system and an exposed ceiling. Extra fiberoptic lines are provided, allowing capacity for future telecommunications and computer needs. Electrical outlets are provided in a high density (approximately five duplex outlets per 100-sf) providing high capacity and close proximity for an unlimited number of equipment changes.

Design Strategies used at MIT Building 16
1. Exposed ceilings with overhead distribution
2. Extra fiberoptic lines
3. Street layout
4. High density of electrical outlets

Table A.5 – Design strategies used at MIT Building 16

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw												▨									
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld							▨			▨		▨		▨							
	Vm																					
Flow	Env																					
	P/T																					

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						▨	▨	▨	▨	▨	▨	▨	▨	▨				▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld							▨			▨		▨		▨							
	Vm	▨	▨	▨	▨	▨																
Flow	Env																					
	P/T																			▨	▨	

User needs for
Building 16, MIT

BUILDING 314 (INDIANAPOLIS, INDIANA)

Originally constructed in the 1920's to serve as assembly plant for luxury automobiles, this 5-story, 600x80-ft cast-in-place concrete building was renovated in 1998 to serve as office and laboratory space. Its strong, heavy structure allowed the renovation to take place without structural rehabilitation, and the long, thin shape allows light to permeate deep into the building, which is ideal for office space.

Because this is a renovation project, many of the building's attributes (e.g. structural characteristics) had impacts, which restrict the use of certain design strategies that could increase the building's capacity to accommodate changes. Some steps toward future flexibility are taken, including exposed ceilings with overhead distribution and the standardization of offices and other rooms to facilitate rearrangement of people. Rooms in laboratories are often built to be the same size, allowing rooms to be considered "modules" that can be easily joined together to create larger rooms. In this case, the rooms are separated by 65" (mid-height) partition walls.

	Design Strategies used at Building 314
1.	Demountable mid-height partitions
2.	Room size standardization
3.	Exposed ceilings with overhead distribution

Table A.6 – Design strategies used at Building 314

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld							▨			▨	▨	▨		▨							
	Vm																					
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld							▨			▨	▨	▨		▨							
	Vm																					
Flow	Env																					
	P/T							▨	▨	▨	▨	▨	▨	▨	▨					▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld							▨			▨	▨	▨		▨							
	Vm																					
Flow	Env																					
	P/T							▨	▨	▨	▨	▨	▨	▨	▨					▨	▨	

User needs for Building 314

9/90 CORPORATE CENTER (FRAMINGHAM, MASSACHUSETTS)

This corporate development is home to an office building leased by Computer Associates, Inc., a worldwide leader in software development, as well as a Staples store, and an upscale hotel. Computer Associates realized that their many computers, running simultaneously in the same space, significantly increased the potential for the heating loads to exceed the cooling capacity of the HVAC system. They requested that space and structure be allocated to support an additional rooftop chiller unit.

While the structural capacity is provided, additional capacity in the vertical shafts is not. Vertical penetrations in buildings are deducted form the usable area of the building, so the owner attempts to create shaft sizes large enough to handle the expected heating/cooling requirements only.

Design Strategies used at 9/90 Corporate Center
1. Structural column overcapacity

Table A.7 – Design strategies used at 9/90 Corporate Center

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld						▨	▨	▨		▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld						▨	▨	▨		▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

**User needs for
9-90 Corporate Center**

GAP, INC. HEADQUARTERS (SAN BRUNO, CALIFORNIA)

Gap's new headquarters was built with the intent of attracting top employees in the San Francisco area, so included in the design is a cafeteria, fitness center, lap pool, and other comfort-providing elements. The building was also designed to maximize thermal efficiency, using a grass-covered roof to provide a thermal buffer, and operable windows.

Nine times a year, Gap changes its fashion lines, requiring teaming areas that can be changed and restructured easily. To sustain this, a raised floor system houses cabling and mechanical ducts, allowing easy rearrangement within the working space.

Design Strategies used at Gap, Inc. Headquarters
1. Access floors housing mechanical ducts

Table A.8 – Design strategies used at Gap, Inc. Headquarters

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

User needs for
Gap, Inc. Headquarters

IGUS FACTORY (COLOGNE, GERMANY)

Igus, a firm that makes injection-molded plastic products, requested that their new manufacturing plant be designed and built to accommodate the flexibility and growth anticipated by the firm in the coming years. The result is a single-story facility that can be built in phases as the company grows and incorporates flexibility in nearly every feature of the structure, enclosure, services, and finish systems. No system could be incorporated into the design that could not be justified in terms of its future economy (e.g. low maintenance, longer life, etc.).

The structural system includes four masts that support large areas of the roof via slender steel rods, eliminating columns in the interior space. The large open space provides a possible exit strategy for Igus, since they could sell the building for other uses (e.g. supermarket).

The enclosure system is constructed of 1x2.25-m aluminum panels that can be removed and interchanged with one another, including wall, window, and door panels. The system easily accommodates future growth and phased development, since new panels can be easily joined.

Services and finish are uniquely intertwined to create office "pods" that can be moved within the large interior space in about 2 weeks time. The soundproofed pods isolate users from manufacturing noise, and have large feet that spread the pod's load, eliminating the need to reinforce the foundation for each move. Pods attach to overhead utility mains to provide power, data, and HVAC service.

Design Strategies used at Igus Factory
1. Column-free zones in structure
2. Office pod system
3. Modular panel cladding system

Table A.9 – Design strategies used at Igus Factory

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw												▨	▨					▨	▨	▨	▨
	Md																					
Capacity	Ld						▨	▨	▨	▨	▨	▨	▨									
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨
Flow	Env																					
	P/T	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨		▨	▨			▨	▨	▨	▨

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨					▨	▨	▨	▨
	Md																					
Capacity	Ld						▨	▨	▨	▨	▨	▨	▨									
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨
Flow	Env			▨	▨	▨	▨	▨	▨	▨									▨	▨	▨	▨
	P/T	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨		▨	▨			▨	▨	▨	▨

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						▨	▨	▨			▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨					▨	▨	▨	▨
	Md	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨
Capacity	Ld						▨	▨	▨	▨	▨	▨	▨									
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨
Flow	Env			▨	▨	▨	▨	▨	▨	▨									▨	▨	▨	▨
	P/T	▨	▨	▨	▨		▨	▨	▨	▨	▨	▨	▨		▨	▨			▨	▨	▨	▨

User needs for
Igus Factory

K. WAYNE SMITH BUILDING (DUBLIN, OHIO)

The K. Wayne Smith building is owned and occupied by the Online Computer Library Center, Inc. (OCLC), who catalogs information about books and periodicals and supplies the information to libraries throughout the country. A former Volkswagen warehouse, the 112,000-sf original building was renovated and expanded in 1997 to create 177,000-sf of offices, conference and training areas, and an employee fitness center. OCLC stated their need for flexibility as a goal during the design phase of this renovation.

To help provide this flexibility in the service and finish systems, a raised floor and accessible modular wiring are used in the office space, providing power and voice/data connections spaced every 15-ft.

Design Strategies used at the K. Wayne Smith Building
1. Raised flooring
2. Accessible modular wiring

Table A.10 – Design strategies used at the K. Wayne Smith Building

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

User needs for
K. Wayne Smith

MASHPEE JUNIOR/SENIOR HIGH SCHOOL (MASHPEE, MASSACHUSETTS)

In an area experiencing high growth in the number of junior and senior high-school students, a school building may fulfill many needs of the students. Also, the longevity of school buildings usually means that the school facilities will have to accommodate the changing needs of students over a long time. Planners of the Mashpee H.S. required special design considerations to create a flexible building to accommodate multiple uses and a diverse population.

The building services are distributed horizontally through the corridors of the building (commonly called a "street layout" or "racetrack"), so additional lines to rooms can be easily attached to the mains. Cable and wiring are run in the ceiling, while data and power connections run alongside classroom walls.

Design Strategies used at Mashpee Junior/Senior High School
1. Street layout

Table A.11 – Design strategies used at Mashpee Junior/Senior High School

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw												▨									
	Md																					
Capacity	Ld										▨		▨									
	Vm																					
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																		▨	▨	▨	▨
	Nw												▨									
	Md																					
Capacity	Ld										▨		▨									
	Vm																					
Flow	Env																					
	P/T																					

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨	▨	▨	▨			▨	▨						▨	▨	▨	▨
	Nw												▨									
	Md																					
Capacity	Ld										▨		▨									
	Vm																					
Flow	Env																					
	P/T																					

User needs for
Mashpee Jr-Sr HS

METRO-DADE CENTER (MIAMI, FLORIDA)

The Metro-Dade Center in Miami is a 31-story public office building for Dade County. Flexibility is needed for the rearrangement of staff within the building. This project is unique because of the building's tall, narrow shape, since many design strategies work best for larger, flatter buildings.

Flexibility is achieved through the use of a poke-through floor system, in which cables to service a given floor are run in open-top troughs in the ceiling plenum of the floor below. Cables are accessed by drilling a hole through the floor, through which the cable is threaded. The cables connect to outlet monuments at workstation groups as required, minimizing the number of required holes in the slab.

Design Strategies used at Metro-Dade Center
1. Poke-through floors

Table A.12 – Design strategies used at Metro-Dade Center

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

User needs for
Metro Dade Center

MOUNT AUBURN HOSPITAL (CAMBRIDGE, MASSACHUSETTS)

Located in Cambridge, MA, Mt. Auburn Hospital is constrained on all sides by major roads and a public park. The original designers of the building realized the impact these site constraints would have on future growth of the facilities, so extra strength was provided in the structural columns and foundation to accommodate future *vertical* expansion.

In 1997, construction was begun on an expansion of the building, adding 2 floors and 12,000-sf of space on top of the existing building. Renovation work was also performed in the basement, as well as finish work on other floors.

Design Strategies used at Mount Auburn Hospital
1. Structural column overcapacity

Table A.13 – Design strategies used at Mount Auburn Hospital

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨								
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld	▨	▨								▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T																		▨	▨	▨	▨

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨	▨				▨	▨	▨	▨
	Nw											▨	▨	▨					▨	▨	▨	▨
	Md																					
Capacity	Ld	▨	▨								▨				▨							
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Flow	Env						▨	▨	▨													
	P/T			▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨							▨	▨	▨				▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld	▨	▨								▨				▨				▨	▨	▨	▨
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Flow	Env						▨	▨	▨													
	P/T			▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨

User needs for
Mt. Auburn Hospital

OWENS CORNING (TOLEDO, OHIO)

Completed in 1998, the new Owens Corning World Headquarters building sits on a 45-acre site on the Maumee River north of downtown Toledo. During the design phase, it was recognized that collaboration among employees was a vital part of the company's activities, and since these collaborating groups were changing frequently (estimated churn rate of 120% annually), the building's services and finish systems must be able to accommodate these changes quickly. The intended goal was to be able to change out 30,000-sf of space over a weekend, without having to contract work to outside companies.

Services and finish are combined in the access floor delivery system used, which creates a plenum beneath the floor where cabling is routed. Cooled air is blown into the plenum, which ventilates the working area through a series of variable-air-volume diffusers. This system allows cables to be easily re-routed and provides controllable ventilation, heating and cooling at any location on the floor. A task-lighting system is also used, which reduces the power needed for the main overhead lighting grid, and provides concentrated, movable light sources at many locations.

Design Strategies used at Owens Corning
1. Access floor delivery system
2. Task lighting system

Table A.14 – Design strategies used at Owens Corning

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

**User needs for
Owens Corning**

REVENUE CANADA BUILDING (SURREY, BRITISH COLUMBIA, CANADA)

Revenue Canada is responsible for revenue generation, customs border services, income redistribution, and trade administration for the Provinces and Territories of Canada. For the design, the administrators of the Surrey Office required flexibility that would accommodate frequent relocations of staff.

An 18-inch high access floor delivery system is used in this four-story building, which houses mechanical ducts, providing a low-pressure, high-volume air supply that can be controlled at the source by building users at each workstation. Air is delivered through the plenum and diffused through vents in the floor; the ducts in the floor carry air to the perimeter of the building.

Design Strategies used at Revenue Canada
1. Access floors housing mechanical ducts

Table A.15 – Design strategies used at Revenue Canada

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

User needs for
Revenue Canada Building

SAN JOAQUIN GENERAL HOSPITAL (SAN JOAQUIN COUNTY, CALIFORNIA)

This hospital recognized the need to keep its cabling and communications systems up to date, and also realized the potential impacts of having to shut down the system for future upgrades.

An advanced cable type (enhanced performance Category 5) is used in combination with other, conventional cable types. By creatively combining state-of-the-art, fiber-optic cable with high-performance, copper-based specialty cable, the hospital has attempted to "future-proof" its facility for many years to come. This project is a good illustration of making a one-to-one replacement of a single component, achieving goals for the future without changing the impacts on and interactions with other systems.

Design Strategies used at San Joaquin General Hospital
1. Enhanced performance cabling system

Table A.16 – Design strategies used at San Joaquin General Hospital

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨								
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld	▨	▨								▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T																		▨	▨	▨	▨

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up										▨		▨	▨	▨				▨	▨	▨	▨
	Nw										▨	▨	▨	▨					▨	▨	▨	▨
	Md																					
Capacity	Ld	▨	▨								▨				▨							
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Flow	Env						▨	▨	▨													
	P/T			▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨					▨		▨	▨	▨				▨	▨	▨	▨
	Nw										▨	▨	▨	▨								
	Md																					
Capacity	Ld	▨	▨								▨				▨				▨	▨	▨	▨
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Flow	Env						▨	▨	▨													
	P/T			▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨

User needs for
San Joaquin General Hospital

STATA COMPLEX, MASSACHUSETTS INSTITUTE OF TECHNOLOGY (CAMBRIDGE, MA)

Construction on this complex of buildings on the MIT campus began in October 1999, and should be completed in 2001. These buildings will be the home of many classrooms, computer laboratories, and the MIT Artificial Intelligence Laboratory, among other facilities. For many of the areas in this complex, MIT desired the flexibility to rearrange the computer and electrical cabling to meet various layout needs.

An access floor delivery system is selected for use in the Stata Complex. Cooled air is pumped into the space beneath the access floor, thus eliminating horizontal supply ductwork, and is then vented at several variable-air-volume (VAV) units placed flush with the floor panels. The VAV-units may have heating coils, can be controlled at small areas and/or at a single location, and may be moved as easily as any floor panel. The raised floor also provides easy access for the rearrangement of cabling.

Design Strategies used at the MIT Stata Complex
1. Small-area VAV units
2. Access floor delivery system

Table A.17 – Design strategies used at the MIT Stata Complex

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨									
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env						▨	▨	▨													
	P/T						▨	▨	▨		▨	▨	▨									

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																		▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env						▨	▨	▨													
	P/T						▨	▨	▨		▨	▨	▨									

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨	▨	▨	▨			▨	▨						▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env						▨	▨	▨													
	P/T						▨	▨	▨		▨	▨	▨									

User needs for
Stata Complex, MIT

STOP & SHOP GROCERY STORE (NORWOOD, MASSACHUSETTS)

The Stop & Shop chain of grocery stores is the largest food retailer in New England, who strives to offer a full range of services to its customers, including video rental, floral arrangements, and even gas stations. In order to remain a leader in a highly competitive industry, Stop & Shop must cater to the every need of the shopper, and frequently rearranges its stores (about every 5-7 years) to help achieve that goal.

While shelves in a store can be easily moved and reassembled, moving a freezer of refrigeration unit is much more difficult. These units require drainage that is typically run beneath the slab on grade. Tearing up the slab to remove old drainage pipes and install new ones poses a major inconvenience on shoppers.

Stop & Shop has incorporated the use of an EVAC© system, much like is used to flush toilets in airplanes. This allows the unit to drain to a small storage tank, which is automatically "flushed" to an overhead drainage system. Moving the freezer unit requires only a new PVC extension from the overhead system to the appropriate unit location, as opposed to concrete slab demolition.

Design Strategies used at the Stop & Shop Grocery
1. Interstitial space beneath structural slab
2. Overhead drainage system

Table A.18 – Design strategies used at the Stop & Shop Grocery

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw			▨									▨									
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T				▨															▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨						▨	▨	▨	
	Nw			▨									▨									
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T	▨			▨					▨	▨				▨					▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨							▨						▨	▨	▨	
	Nw			▨									▨									
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T	▨			▨					▨	▨				▨					▨	▨	

User needs for
Stop&Shop - Norwood

SUMMIT PROPERTIES APARTMENTS (CHARLOTTE, NC)

Summit Properties is a builder of large, "Class-A" apartments and developments in the South and East of the United States. They recognize the importance of the changing computer and communications needs for their tenants and clients.

To accommodate future service distribution to the apartment units, Summit installs a system of vacant ¾"-conduit to each apartment, originating at a single location in the building. This allows the simplest means of providing later services to the apartment units without having to demolish interior finish. By installing this conduit during the building's initial construction, the cost is only a negligible increase.

Design Strategies used at Summit Properties
1. Extra vacant conduit

Table A.19 – Design strategies used at Summit Properties

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm									▨	▨	▨	▨	▨								
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																		▨	▨		
	Nw											▨	▨									
	Md																					
Capacity	Ld																					
	Vm									▨	▨	▨	▨	▨								
Flow	Env																					
	P/T						▨	▨	▨	▨	▨				▨	▨				▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨								▨					▨	▨	▨	▨
	Nw											▨	▨									
	Md																					
Capacity	Ld																					
	Vm									▨	▨	▨	▨	▨								
Flow	Env																					
	P/T						▨	▨	▨	▨	▨				▨	▨				▨	▨	

User needs for
Summit Properties Apartments

TOYOTA MOTOR CORP. PARTS CENTER (ONTARIO, CALIFORNIA)

Warehouses epitomize the idea of churn in buildings. They serve to receive and store goods, often of many types, which are then removed and replaced with other goods. In 1997, the Toyota Corporation built a 760,000-sf facility to house parts for assembling motors, at a construction cost of about $42/sf (compared to $17/sf for a typical parts warehouse). Several systems in the building lead to characterization of the facility as a "hi-tech" warehouse, such as special shrinkage-compensating concrete that reduces by a factor of ten the number of control joints needed in the slab, reducing wear and deterioration. Also, a special fire-suppression system was built, complete with its own 300,000-gal water tower.

Many parts stored by Toyota are made of plastics, which must be stored at facilities that conform to certain code restrictions regarding fire suppression. Toyota requires the ability to change and rearrange the contents of the warehouse. Therefore, extra-fast-acting sprinkler heads are used, which are set to go off when the ambient temperature reaches 165-degrees F. This allows all kinds of Toyota's plastic parts to be stored throughout the building.

Design Strategies used at the Toyota Motor Parts Facility
1. Extra-fast acting sprinklers

Table A.20 – Design strategies used at the Toyota Motor Parts Facility

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T															▨						

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm	▨	▨	▨	▨	▨																
Flow	Env																					
	P/T															▨						

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨																
	Nw																					
	Md																					
Capacity	Ld																					
	Vm	▨	▨	▨	▨	▨																
Flow	Env																					
	P/T															▨						

User needs for
Toyota Motor Parts Facility

UNILEVER RESEARCH (BEDFORDSHIRE, UNITED KINGDOM)

This two-story food-research facility was constructed in 1995 for the Unilever company to house offices and laboratory space on their research campus. The layout allows rooms to be combined easily by knocking out walls, forming larger spaces. In order to avoid destroying cables that are distributed through walls, the service and finish systems needed to be decoupled.

Cabling is distributed horizontally through hung ceilings, then put into surface raceways that can be easily removed and accessed. This also gives Unilever the ability to incorporate new cables and services into existing rooms, without damaging the finish.

Design Strategies used at Unilever Research
1. Single/multi-channel surface raceways

Table A.21 – Design strategies used at Unilever Research

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld							▨			▨	▨	▨		▨							
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld							▨			▨	▨	▨		▨							
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨	▨					▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld							▨			▨	▨	▨		▨							
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨	▨					▨	▨	

User needs for
Unilever Research

US NAVY OPERATIONAL TRAINER FACILITY (SAN DIEGO, CALIFORNIA)

This facility is used to train Navy personnel to defend against and attack enemy submarines, and utilizes many large, electronic trainers. The building design places classrooms and offices at the perimeter of the building and two large training rooms at the center that house the electronic trainers. Since this is a high-tech military facility, it has strict security needs that must be taken into account when designing for flexibility (i.e. no flexible design may compromise the facility's security).

The facility jointly utilizes access flooring and full-height demountable partitions that are positioned between the raised floor and the hung ceiling, allowing uninterrupted horizontal distribution of cabling and utilities, as well as rearrangement of the flexible space.

Design Strategies used at the US Navy Operational Trainer Facility
1. Raised flooring
2. Demountable full-height partition walls

Table A.22 – Design strategies used at the US Navy Operational Trainer Facility

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up													▨								
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld													▨								
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨
Flow	Env																					
	P/T																					

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨	▨	▨	▨			▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld													▨								
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨
Flow	Env																					
	P/T									▨	▨		▨	▨								

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld													▨								
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨
Flow	Env																					
	P/T									▨	▨		▨	▨								

User needs for
USNavy Antisub Training

Needs Framework

Short-term needs (1-5 years)

		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw												▨	▨								
	Md																					
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env																					
	P/T																					

Needs Framework

Medium-term needs (5-15 years)

		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md																					
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env																					
	P/T							▨			▨		▨	▨	▨					▨	▨	

Long-term needs (15-30 years)

		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨							▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md																					
Capacity	Ld							▨			▨				▨							
	Vm																					
Flow	Env																					
	P/T							▨			▨		▨	▨	▨					▨	▨	

**User needs for
Typical R&D Lab**

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up											▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨						▨	▨	▨					▨	▨	▨	▨
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld										▨	▨	▨									
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨	▨	▨	▨						▨	▨	

User needs for Typical Office

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨								
	Nw												▨	▨								
	Md																					
Capacity	Ld										▨				▨							
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨			▨	▨	▨			▨	▨	▨	▨

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md																					
Capacity	Ld										▨				▨							
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨			▨	▨	▨			▨	▨	▨	▨

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨	▨	▨	▨				▨	▨					▨	▨	▨	▨
	Nw												▨	▨								
	Md																					
Capacity	Ld										▨				▨							
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨			▨	▨	▨			▨	▨	▨	▨

User needs for
Typ. Manufacturing-Fabrication

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																		▨	▨		
	Nw											▨	▨									
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨				▨	▨				▨	▨	

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨								▨					▨	▨	▨	▨
	Nw											▨	▨									
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨	▨				▨	▨				▨	▨	

User needs for
Typical Residential

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw												▨									
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																		▨	▨	▨	▨
	Nw												▨	▨								
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨	▨	▨	▨			▨	▨						▨	▨	▨	▨
	Nw												▨	▨								
	Md																					
Capacity	Ld																					
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Flow	Env																					
	P/T																					

User needs for
Typical Educational Building

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨								
	Nw											▨	▨	▨								
	Md																					
Capacity	Ld	▨	▨								▨				▨							
	Vm																					
Flow	Env						▨	▨	▨													
	P/T																		▨	▨	▨	▨

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up												▨	▨	▨				▨	▨	▨	▨
	Nw											▨	▨	▨					▨	▨	▨	▨
	Md																					
Capacity	Ld	▨	▨								▨				▨							
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Flow	Env						▨	▨	▨													
	P/T			▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨							▨	▨	▨				▨	▨	▨	▨
	Nw											▨	▨	▨					▨	▨	▨	▨
	Md																					
Capacity	Ld	▨	▨								▨				▨				▨	▨	▨	▨
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Flow	Env						▨	▨	▨													
	P/T			▨	▨		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨

User needs for
Typical In-patient Medical

Needs Framework

		Short-term needs (1-5 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																		▨	▨	▨	▨
	Nw				▨					▨		▨	▨	▨							▨	
	Md																					
Capacity	Ld									▨												
	Vm																					
Flow	Env																					
	P/T						▨	▨	▨	▨									▨	▨	▨	▨

Needs Framework

		Medium-term needs (5-15 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up													▨					▨	▨	▨	▨
	Nw				▨					▨		▨	▨	▨							▨	
	Md																					
Capacity	Ld									▨												
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨
Flow	Env																					
	P/T						▨	▨	▨	▨									▨	▨	▨	▨

		Long-term needs (15-30 years)																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up					▨	▨	▨	▨	▨		▨	▨	▨			▨		▨	▨	▨	▨
	Nw				▨					▨		▨	▨	▨							▨	
	Md																					
Capacity	Ld									▨												
	Vm	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨
Flow	Env																					
	P/T						▨	▨	▨	▨									▨	▨	▨	▨

User needs for
Typical High-end Retail

APPENDIX B

Descriptions and relevant data for design strategies examined in this research, and achievement matrices for each design strategy.

List of Design Strategy Descriptions and Achievement Matrices

Design Strategy: FALSE SLAB

Facilities using design strategy:

Source of design strategy: Hines Interests, Ltd.

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services**

DESCRIPTION OF STRATEGY: In areas where under-floor utilities require future access, but are located either immediately above an occupied space or a mat slab, a second slab is poured, sandwiching a layer of sand up to two feet thick, in which the utility pipes are placed. This allows the upper slab to be easily opened at a later date, without damaging the structural integrity of the floor or foundation. The slab is typically poured over the entire floor plan. The lower slab is structural, and the upper slab is poured as if it were a typical slab on grade.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc): Concrete structures, renovation projects only where column capacity is strong enough to accommodate new dead load.
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: no
  - Ease of construction: easy
  - Construction duration: lengthened – must wait for curing of lower slab to be completed before upper slab can begin
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes: after lower curing has completed, place pipes, test, infill with sand, place concrete reinforcing, pour concrete, finish
  - Financial cost: Reinforced WWF 4” concrete slab – add $3.62/sf
    - Rest of cost is the same

Operations and Maintenance

Financial cost: not applicable

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Demolition cost is $1.03/sf, as opposed to demolition of a mat foundation, which is $68.23/sf.

Reconstruction is $3.62/sf, while a mat slab is about $20/sf

Total is $4.23 per square foot of footprint

Downtime: shortened

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up														X							
	Nw														X							
	Md														X							
Capacity	Ld														X							
	Vm														X							
Flow	Env																					
	P/T														X							

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for False Slab

Design Strategy: EXTERIOR WALL CONCRETE KNOCKOUT PANELS

Facilities using design strategy:

Source of design strategy: Industrial Developments International, Inc.

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure Enclosure**

ACHIEVES FLEXIBILITY IN SYSTEM: **Enclosure**

DESCRIPTION OF STRATEGY: In concrete walls, either cast-in-place or tilt-up, structural capacity is provided in the reinforcing steel to accommodate loads when the wall is either (a) whole, or (b) missing a particular segment ("panel") where a door could be placed. Rustification strips are glued to the concrete formwork, creating an architectural impression that indicates where incisions would be made, when the concrete panel is to be removed. This strategy is frequently used in industrial buildings where future doors may be needed or wanted for the passage of vehicles or cargo. Panels would typically be located at the quarter-points of the wall's length.

First Construction

System Design

Difficulty: simple

Restrictions (building type, materials, layouts, etc): Concrete exterior walls only.

Design cost concerns: none

System Construction

Skills and training procurement: none

Ease of construction: easy

Construction duration: no impact

Procurement concerns: yes – rustification strips

Safety concerns: no

Process changes: align, place and glue rustification strips to formwork

Financial cost: rustification strips - $1.00/lf. Extra rebar material cost is negligible. Total cost increase is negligible.

Operations and Maintenance

Financial cost: not applicable

Accessibility for operations and maintenance: not applicable

Irrevocability of commitment: none

Change Implementation

Financial cost: For a structural concrete wall, with a panel of 10'x10', the estimated cost to cut, remove, and haul away material for 1 panel is $7200.

To make the same alterations to a brick façade would be cost prohibitive.

Downtime: shortened

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw			X	X																	
	Md			X	X																	
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T			X	X																	

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw			X	X																	
	Md			X	X																	
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T			X	X																	

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for
Exterior Wall Knockout Panels

Design Strategy: INTERSTITIAL MEZZANINE FLOOR RACK SYSTEM

Facilities using design strategy:

Source of design strategy: Industrial Developments International, Inc.

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure**

ACHIEVES FLEXIBILITY IN SYSTEM: **Structure**

DESCRIPTION OF STRATEGY: In areas where the ceiling height permits, a rack system to insert an interstitial floor can be used. This may be done in one of three ways:

(a) if the structural steel columns are sufficiently strong, floor spans may be made form column to column, and covered by the decking;

(b) if additional columns are needed, the floor must be cut and a footing and column installed, then the floor is replaced (unless footings were placed appropriately for new columns at the time of initial construction).

(c) if the slab's load capacity is satisfactory, the prefabricated rack system's columns may bear directly on the slab.

The cost of options (a) and (c) are approximately $10-15 per square foot. The cost of option (b) is dependent on many factors with respect to the footings that must be constructed. This design strategy is most often used in warehouses where expanded office space is needed.

First Construction

System Design

Difficulty: simple

Restrictions (building type, materials, layouts, etc): Area where mezzanine will be created must have a two-story floor height

Design cost concerns: none

System Construction

Skills and training procurement: none

Ease of construction: easy

Construction duration: shortened—only extra time needed for additional footings

Procurement concerns: no

Safety concerns: no

Process changes:

Financial cost: extra capacity in columns – negligible

Connections prepared – add $2000

Operations and Maintenance

Financial cost: not applicable

Accessibility for operations and maintenance: no change

Irrevocability of commitment: none

Change Implementation

Financial cost: $10-15/sf (assume extra capacity in columns and footings)

For half of a single floor (area = 12,450-sf):

Total cost = $12.50 * 12,450 = $155,625

It is assumed that the cost of strengthening foundations would be cost prohibitive in most construction projects.

Downtime: no impact

Tasks: for prefabricated rack system on sufficiently strong slabs, new columns may simply bear on floor. Others involve welding new beams to columns or attaching column bases to footings

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw		X																			
	Md		X																			
Capacity	Ld																					
	Vm		X																			
Flow	Env																					
	P/T		X																			

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Interstitial Mezzanine Floor

Design Strategy: Z-LAYOUT CONFIGURATION

Facilities using design strategy:

Source of design strategy: Lincoln Property Co.

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure** **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: Used most often in speculative office buildings, this strategy involves putting a core of building services at the center of the building, from which extend two parallel corridors in opposite directions, originating at opposite sides of the core and terminating at opposite sides of the building. The interior finish in remaining areas is left untouched. This allows the developer to install a certain amount of service distribution throughout the building, without committing excessive finish resources.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc): works best for buildings that are squarish or rectangular, maximizing floor area while limiting the distance from the core and/or corridors to the building perimeter
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: Variable about zero – this simply changes the extent of space improvements provided by a developer and a tenant

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: not applicable

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Variable about zero

Downtime: no impact—changes typically made while affected space is unoccupied

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw		X																			
	Md		X				X	X	X	X	X	X	X	X	X	X		X				
Capacity	Ld																					
	Vm																					
Flow	Env						X	X	X	X	X	X	X	X	X	X		X				
	P/T		X				X	X	X	X	X	X	X	X	X	X		X				

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw		O																	X	X	X
	Md																					
Capacity	Ld									X	X	X	X	X	X	X						
	Vm																					
Flow	Env						X	X	X	X	X	X	X	X	X	X				X	X	X
	P/T						X	X	X	X	X	X	X	X	X	X				X	X	X

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Z-Layout

Design Strategy: STRUCTURAL "LADDER" ASSEMBLY SYSTEM

Facilities using design strategy:

Source of design strategy: National Development of New England

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure**

ACHIEVES FLEXIBILITY IN SYSTEM: **Structure**

DESCRIPTION OF STRATEGY: Structural beams are used throughout the floor construction of a composite system (corrugated steel deck with CIP concrete topping); no open-web joists are used. This allows the load capacity of the floor to be increased at a later date by welding steel plate to the bottom flange, which is prohibited by building codes for open-web joists.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc): steel structure
  - Design cost concerns: there may be some increase in floor-to-floor height, since horizontal distribution of utilities could pass through the webs of open-web joists, but must pass beneath beams
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: no
  - Safety concerns: later welding would have to be done overhead of worker
  - Process changes:
  - Financial cost: increase of $1.00/sf (Structural ladder costs $7.00/sf net, while open web joists cost $6.00/sf)

Operations and Maintenance

Financial cost: not applicable

Accessibility for operations and maintenance: not applicable

Irrevocability of commitment: total commitment

Change Implementation

Financial cost:

Design Live Load	Open-web Joists	Steel Beams
Initial construction, 80-psf:	$6.00/sf	$7.00/sf
Upgrade from 80 – 100-psf:	Cannot be done	$0.20/sf
Upgrade from 100 – 125-psf:	Cannot be done	$2.00/sf*

* *Code restrictions mandate that floors designed to accommodate distributed live loads in this range must also accommodate higher point loads, requiring added capacity*

Downtime:

Tasks: expose beams, weld plates, fireproof, replace ceiling

Accessibility for renovation: no change worsened improved access moderately difficult access, since steel beams will be concealed behind ceilings and fire protection

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up		X																			
	Nw		X																			
	Md		X																			
Capacity	Ld		X																			
	Vm																					
Flow	Env						O	O	O		O	O	O	O	O	O						
	P/T						O	O	O		O	O	O	O	O	O						

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Structural Ladder

Design Strategy: **CENTRALIZED CONFIGURATION**

Facilities using design strategy:

Source of design strategy: Trammell Crow Co.

DESIGN STRATEGY APPLIED TO SYSTEM:	**Structure**		
ACHIEVES FLEXIBILITY IN SYSTEM:	**Structure**	**Services**	**Finish**

DESCRIPTION OF STRATEGY: Like the Z-layout configuration, without the two corridors. Frequently used in speculative office buildings, a utility core is constructed at the center of the building. Once a tenant has committed to the space, the utilities are extended and distributed from the core to best accommodate the tenant's needs. The interior finish in remaining areas is left untouched. This allows the developer to install a very limited amount of service distribution throughout the building, without committing excessive finish resources.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc): works best for buildings that are squarish in plan, maximizing floor area while limiting the distance from the core to the building perimeter
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: Variable about zero – this simply changes the extent of space improvements provided by a developer and a tenant.

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: no change

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Variable about zero

Downtime: no impact

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw		X																			
	Md		X				X	X	X	X	X	X	X	X	X	X		X				
Capacity	Ld																					
	Vm																					
Flow	Env						X	X	X	X	X	X	X	X	X	X		X				
	P/T		X				X	X	X	X	X	X	X	X	X	X		X				

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw		X																			
	Md		X																			
Capacity	Ld						O	O	O													
	Vm																					
Flow	Env						X	X	X	X	X	X	X	X	X	X						
	P/T		X				X	X	X	X	X	X	X	X	X	X						

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Centralized Layout

Design Strategy: MULTI-CHANNEL SURFACE RACEWAYS

Facilities using design strategy: Unilever Research

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services** **Finish**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: Surface raceways are hollow plastic finish components, which appear to be molding trim, but actually carry horizontal wiring distribution throughout an occupied space. Raceways are often located at the baseboard level, ceiling level, or at a height of about four feet from the floor.

First Construction

System Design
  Difficulty: simple
  Restrictions (building type, materials, layouts, etc):
  Design cost concerns: none

System Construction
  Skills and training procurement: none
  Ease of construction: easy
  Construction duration: no impact
  Procurement concerns: yes
  Safety concerns: no
  Process changes: Rather than wiring behind the walls before finished surfaces are installed, raceways are installed on top of the finished surface. The raceways are anchored to walls with screws. Wires are pulled through the raceways, or inserted through a continuous slot along the length of the raceway sections.

Financial cost: $5.00/lf installed, approximately 0.25-lf per sf of plan area.

Operations and Maintenance

Financial cost: not significant – damaged raceways may need to be replaced, for aesthetic purposes

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: Reduced cost for demolition, repair, and refinish by $9/lf of change

Downtime: shortened – could be performed during off-hours for many buildings

Tasks: remove/replace/insert additional wires, either by pulling through raceways or accessing through a continuous slot along the length of the raceway sections.

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up									X	X	X	X	X								
	Nw									X	X	X	X	X								
	Md																					
Capacity	Ld									X	X	X	X	X								
	Vm									X	X	X	X	X						X	X	
Flow	Env									X	X	X	X	X						X	X	
	P/T									X	X	X	X	X						X	X	

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up									X	X	X	X	X								
	Nw									X	X	X	X	X								
	Md																					
Capacity	Ld									X	X	X	X	X								
	Vm									X	X	X	X	X						X	X	
Flow	Env									X	X	X	X	X						X	X	
	P/T									X	X	X	X	X						X	X	

Design strategy achievements for Surface Raceways

Design Strategy: OVERHEAD CABLE TRAYS

Facilities using design strategy:

Source of design strategy: Wiremold, Inc.

DESIGN STRATEGY APPLIED TO SYSTEM:	**Services**
ACHIEVES FLEXIBILITY IN SYSTEM:	**Services**

DESCRIPTION OF STRATEGY: Rather than using conduit to distribute wiring, long trays are installed behind a suspended ceiling, providing easy access for changes. Types of changes this is expected to aid include addition of wires and connections, as well as rearrangement of wiring terminals.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc): a suspended ceiling should be used to improve access to cable trays, rather than drywall ceiling
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: yes
  - Safety concerns: no
  - Process changes: anchor tray hangers to overhead structure, hang cable trays, lay wires
  - Financial cost: estimated by Wiremold to be $400 per 12’ length of tray, installed. For a 125,000-sf building, assume 6,000-lf of tray => $200,000 total.

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: reduced demolition costs of approximately $9.00 per lf

Downtime: shortened

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up									X	X	X	X	X						X	X	
	Nw									X	X	X	X	X						X	X	
	Md																					
Capacity	Ld									X	X	X	X	X								
	Vm									X	X	X	X	X						X	X	
Flow	Env									X	X	X	X	X						X	X	
	P/T									X	X	X	X	X						X	X	

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Overhead Cable Trays

Design Strategy: STRUCTURAL COLUMN OVERCAPACITY

Facilities using design strategy: Mt. Auburn Hospital, 9/90 Corporate Center

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM:	**Structure**	
ACHIEVES FLEXIBILITY IN SYSTEM:	**Structure**	**Services**

DESCRIPTION OF STRATEGY: The vertical structural system (columns and footings) of a building is designed to carry additional dead loads beyond what is currently expected. This strategy is often applied when users expect to need additional room for growth, but are tightly confined to a certain site area. Often this strategy is applied only to selected columns (i.e. for increased roof loads, like extra rooftop chillers).

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact – no change from normal structural construction time
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes: none
  - Financial cost: Negligible additional material cost

Operations and Maintenance

Financial cost: not applicable

Accessibility for operations and maintenance: not applicable

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Alternative is cost prohibitive –there is virtually no cost to strengthen columns at initial construction, which is especially significant when compared to the very high cost of retrofitting columns to add strength

Downtime: shortened

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw						X	X	X													
	Md	X	X				X	X	X													
Capacity	Ld	X	X				X	X	X													
	Vm	X	X				X	X	X													
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Structural Overcapacity

Design Strategy: **OVERSIZED VERTICAL DISTRIBUTION SHAFTS**

Facilities using design strategy: 270 Albany St.

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services**

DESCRIPTION OF STRATEGY: By increasing the size of the vertical distribution shafts, changes to vertical distribution are made easier. Extra space in the shaft also allows new services to be added to the building without coring through slabs to distribute between floors, and improves access and maintenance to services in these areas. For a rented building, this increase in size comes at a loss of rentable square footage to the tenant, and therefore reduced rent payments to a building owner.

First Construction

- System Design
    - Difficulty: simple
    - Restrictions (building type, materials, layouts, etc):
    - Design cost concerns: none
- System Construction
    - Skills and training procurement: none
    - Ease of construction: easy
    - Construction duration: no impact – no change from smaller shafts
    - Procurement concerns: no
    - Safety concerns: no
    - Process changes: none
    - Financial cost: Variable about zero - material cost increase is minimal in interior finish systems

Operations and Maintenance

Financial cost: decreased

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: $0.

Downtime: shortened

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X	X	X	X	X	X	X	X						
	Nw						X	X	X	X	X	X	X	X	X	X						
	Md						X	X	X	X	X	X	X	X	X	X						
Capacity	Ld																					
	Vm						X	X	X	X	X	X	X	X	X	X						
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Oversized Vertical Shafts

Design Strategy: TWO END CORE CONFIGURATION

Facilities using design strategy: Abbott Laboratories

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM:	**Structure**	**Services**	
ACHIEVES FLEXIBILITY IN SYSTEM:	**Structure**		**Finish**

DESCRIPTION OF STRATEGY: In this layout, two utility cores are constructed at opposite ends of a rectangular building, providing a source for the horizontal distribution. This provides a larger continuous shape of undisrupted space for variable floor plans than buildings with centralized utility cores.

First Construction

- System Design
    - Difficulty: simple
    - Restrictions (building type, materials, layouts, etc): Works best for rectangular buildings
    - Design cost concerns: none
- System Construction
    - Skills and training procurement: none
    - Ease of construction: easy
    - Construction duration: no impact
    - Procurement concerns: no
    - Safety concerns: no
    - Process changes:
    - Financial cost: Variable about zero – there may be a change in the extent of space improvements provided by a developer and a tenant.

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: no change

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Variable about zero

Downtime: shortened

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw		X																			
	Md		X				X	X	X	X	X	X	X	X	X	X		X				
Capacity	Ld																					
	Vm		O		O															X	X	
Flow	Env		O				X	X	X	X	X	X	X	X	X	X		X		X	X	
	P/T		X				X	X	X	X	X	X	X	X	X	X		X		X	X	

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X	X	X	X	X	X	X	X	X	X				
	Nw		X																			
	Md		X																			
Capacity	Ld																					
	Vm																			X	X	
Flow	Env						X	X	X	X	X	X	X	X	X	X		X		X	X	
	P/T		X				X	X	X	X	X	X	X	X	X	X		X		X	X	

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Two-end Core Layout

Design Strategy: RAISED FLOORING

Facilities using design strategy: Abbott Laboratories

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Finish**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: Steel or concrete panels are supported some distance off the floor (typically 6"-1'6" for offices) on pedestals, providing space in which wiring systems can be distributed and accessed easily. Floor panels are typically 24" square in plan and 2" deep, and are fastened to the pedestals with machine screws. This type of flooring system is usually installed in areas where a significant amount of rearrangement occurs in the finish systems. Of major concern, however, is that doorways, elevators, and areas where there are no raised floors align in height with the raised floor areas.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc): doors, elevators, and floor areas adjacent to the raised floor area must align with the height of the raised floor.
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: difficult
  - Construction duration: lengthened
  - Procurement concerns: yes, proper components must be procured
  - Safety concerns: no
  - Process changes: mark and place pedestal, epoxy to floor, adjust pedestal height, place and fasten panel, insert machine screws, place finish surface
  - Financial cost: $5.00/sf installed

Operations and Maintenance

Financial cost: decreased – improved access for O&M on wiring systems and for finish surface, since a modular finish system will be needed for access to individual panels

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: demolition costs of rewiring conventional systems are about $9.00/lf of wire

Downtime: shortened

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up										X	X	X	X	X				X			
	Nw										X	X	X	X	X				X	X		X
	Md										X	X	X	X	X				X			
Capacity	Ld										X	X	X	X	X							
	Vm																			X	X	
Flow	Env																			X	X	X
	P/T										X	X	X	X	X				X	X	X	X

Design strategy achievements for Raised Flooring

Design Strategy: DEMOUNTABLE MID-HEIGHT PARTITIONS

Facilities using design strategy: Abbott Laboratories, Owens Corning World HQ

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Finish**

ACHIEVES FLEXIBILITY IN SYSTEM: **Finish**

DESCRIPTION OF STRATEGY: These partition systems are free standing and unanchored, and are easily rearranged for new layouts in open-plan areas. Through a reduced spatial interaction, these partitions allow heating, ventilation, and air conditioning services to be passed through a space without disruption.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: difficult
  - Construction duration: no impact
  - Procurement concerns: yes
  - Safety concerns: no
  - Process changes: depends on system used
  - Financial cost: approximately $60.00 per linear foot of wall = $6.00/sf of plan, plus labor of $5.00/sf
    - Conventional drywall = $2.00/sf, plus $5.00/sf for labor
      - Net change = +$4.00/sf

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: no change

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: no demolition costs (savings of $9.00/lf compared to drywall)

Downtime: shortened

Tasks:

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																			X	X	
	Nw																			X	X	
	Md																					
Capacity	Ld																					
	Vm																			X	X	
Flow	Env																			X	X	
	P/T																			X	X	

Design strategy achievements for Mid-height Partitions

Design Strategy: **DEMOUNTABLE FULL-HEIGHT PARTITION SYSTEMS**

Facilities using design strategy: Abbott Laboratories

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Finish**

ACHIEVES FLEXIBILITY IN SYSTEM: **Finish**

DESCRIPTION OF STRATEGY: These partition systems are either free-standing or anchored to walls, ceiling tracks, and/or the floor, and are easily rearranged for new layouts in open-plan areas. Unlike mid-height partition systems, these do not provide a reduced spatial interaction to allow heating, ventilation, or air conditioning services to be passed through a space without disruption.

First Construction

System Design

Difficulty: simple

Restrictions (building type, materials, layouts, etc):

Design cost concerns: none

System Construction

Skills and training procurement: none

Ease of construction: difficult

Construction duration: no impact

Procurement concerns: yes

Safety concerns: no

Process changes: depends on system used

Financial cost: \$35.00/lf of wall = \$3.50/sf of plan, plus labor of \$5.00/sf

Conventional drywall = \$2.00/sf, plus \$5.00/sf for labor

Net change = +\$1.50/sf, initially

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: no change

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: no demolition costs (savings of $9.00 compared to drywall)

Downtime: shortened

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																			X	X	
	Nw																			X	X	O
	Md																					
Capacity	Ld																					
	Vm																			X	X	
Flow	Env																			X	X	
	P/T						O	O	O	O						O				X	X	

Design strategy achievements for Full-height Partitions

Design Strategy: **<u>MONOBLOCK PARTITION SYSTEMS</u>**

Facilities using design strategy:

Source of design strategy: PSL Partition Systems, Ltd. (vendor)

DESIGN STRATEGY APPLIED TO SYSTEM: **Finish**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: These partitions are prefabricated at a factory and arrive on site with all finish components and framing intact. Partitions anchor to continuous carpet with velcro patches, and to the metal grid of suspended ceilings using special clips. Panels are interchangeable, and include windows and doors, as well as walls with channels for routing electrical wiring and telephone cables.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc): requires a suspended ceiling, no curved panels
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: difficult
  - Construction duration: no impact
  - Procurement concerns: yes
  - Safety concerns: no
  - Process changes:
  - Financial cost: approximately $60.00 per linear foot of wall = $6.00/sf of plan, plus labor of $5.00/sf
    - Conventional drywall = $2.00/sf, plus $5.00/sf for labor
      - Net change = +$4.00/sf, initially

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: no change

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: no demolition costs (savings of $9.00/lf compared to drywall)

Downtime: shortened

Tasks:

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up										X	X	X							X	X	
	Nw																			X	X	
	Md																					
Capacity	Ld										X	X	X									
	Vm										X	X	X							X	X	
Flow	Env										X	X	X							X	X	O
	P/T										X	X	X							X	X	

Design strategy achievements for Monoblock Partition Units

Design Strategy: SITE-FIXED PANEL PARTITION SYSTEM

Facilities using design strategy:

Source of design strategy: PSL Partition Systems, Ltd. (vendor)

DESIGN STRATEGY APPLIED TO SYSTEM: **Finish**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: These panels are prefabricated with a finished surface on one side, but are not attached to a frame at the time of arrival. The frame is constructed from special steel studs spaced every two feet on center, to which hangers are attached to provide arms like a tree. Clips are attached to the back face of the panels with a mallet, which rest on the hangers and suspend the panel off the floor. Panels are easily removed at a later date by lifting straight up, releasing the clips from the hangers, providing behind-the-wall access to wiring.

First Construction

System Design

Difficulty: simple

Restrictions (building type, materials, layouts, etc):

Design cost concerns: none

System Construction

Skills and training procurement:

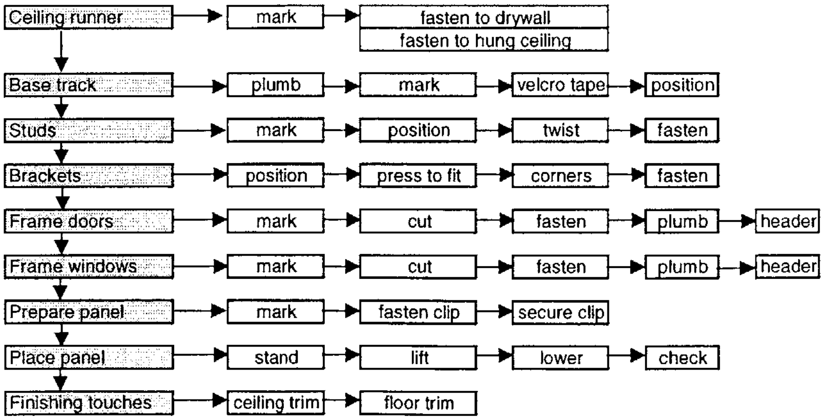
Ease of construction: difficult

Construction duration: no impact

Procurement concerns: yes

Safety concerns: no

Process changes:



Financial cost: material is $20.00/lf = $2.00/sf of plan, plus labor of $5.00/sf

Conventional drywall = $2.00/sf, plus $5.00/sf for labor

Net change = zero

Operations and Maintenance

Financial cost: no impact on O&M

Accessibility for operations and maintenance: no change improved worsened access not applicable easy access

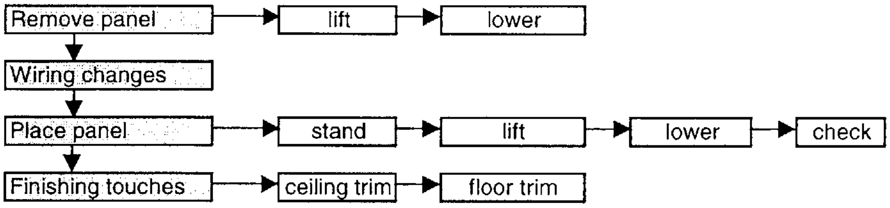
Irrevocability of commitment: none total significant commitment no commitment

Change Implementation

Financial cost: demolition costs savings of 2.25/sf compared to drywall demolition

Downtime: shortened

Tasks:



Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up										X	X	X							X		
	Nw																			X		
	Md																					
Capacity	Ld										X	X	X									
	Vm										X	X	X							X		
Flow	Env										X	X	X							X		O
	P/T										X	X	X							X		

Design strategy achievements for Site-fixed Panel Partitions

Design Strategy: UTILITY RISERS AT COLUMNS

Facilities using design strategy: Abbott Laboratories

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: Utilities such as plumbing and electricity, enter the facility through space underneath the floor, and are distributed throughout the floor to access panels at the base of columns. The primary flexibility allowed by this strategy comes from being able to place equipment at any location on the floor and be within a certain minimum distance from all necessary utilities. At Abbott Laboratories, the open-plan space is divided into manufacturing and office space. This strategy allows Abbott's demountable walls to be placed anywhere on the floor without limiting access to the utilities.

First Construction

- System Design
  - Difficulty: difficult
  - Restrictions (building type, materials, layouts, etc): requires a raised floor
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: lengthened
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: Variable about zero

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: no change

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: reduced, compared to having to run new distribution to equipment

Assuming distance is now half what it was before, a change in electrical wiring saves $4.50/lf ($9/2) and plumbing saves $6/lf ($12/2), with one linear foot of change per 25 sf of area = savings of $0.42/sf

Downtime: shortened

Tasks: disconnect, move machinery, reconnect

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up		O																			
	Nw		O																			
	Md																					
Capacity	Ld									X	X	X	X	X	X	X						
	Vm																			X		
Flow	Env		O							X	X	X	X	X	X	X				X	X	
	P/T		O							X	X	X	X	X	X	X				X	X	

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

**Design strategy achievements for
Utility Risers at Columns**

Design Strategy: **ROOM SIZE STANDARDIZATION**

Facilities using design strategy: Building 314, 270 Albany St.

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: By making rooms in the building into a standard module size, changes may be made to combine rooms into spaces of different shapes and sizes. This is often done with lab spaces, since the amount of space required for researchers differs for each research project.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: Variable about zero

Operations and Maintenance

Financial cost: Not applicable

Accessibility for operations and maintenance: no change

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Variable about zero

Downtime: no impact

Tasks:

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T						X	X	X	X	X	X	X	X	X	X	X			X	X	

Design strategy achievements for
Room Size Standardization

Design Strategy: **COLUMN-FREE ZONES IN STRUCTURE**

Facilities using design strategy: Igus Factory

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure**

ACHIEVES FLEXIBILITY IN SYSTEM: **Structure** **Finish**

DESCRIPTION OF STRATEGY: Large areas unobstructed by columns allow major changes to be made to the interior finish systems; the larger the unobstructed space, the more free arrangement allowed. This can be accomplished through a variety of designs which can vary in complexity. The design chosen by the Igus Factory involves four tower-like masts, from which extend slender, steel tension members used to support the roof. Should the need arise to strengthen the structure, installation of columns is easily accomplished.

First Construction

- System Design
  - Difficulty: difficult
  - Restrictions (building type, materials, layouts, etc): since concrete becomes inefficient at spans of 30-40 feet, structural metal is recommended
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: difficult
  - Construction duration: no impact
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: Very expensive – Sample base cost to suspend one roof of 25000-sf is $1,225,000.

Operations and Maintenance

Financial cost: Not applicable

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Variable about zero

Downtime: no impact

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw		X																			
	Md																					
Capacity	Ld																					
	Vm																		X	X	X	X
Flow	Env		X																X	X	X	X
	P/T		X																X	X	X	X

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Column-free Zones

Design Strategy: <u>OFFICE POD SYSTEM</u>

Facilities using design strategy: Igus Factory

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services** **Finish**

ACHIEVES FLEXIBILITY IN SYSTEM: **Structure** **Services** **Finish**

DESCRIPTION OF STRATEGY: <u>Large modular "pods" containing all office space services and finishes can be built, disassembled, and reassembled within a space in a relatively short time. This is especially effective in areas where there are mixed use, which needs to be segregated (e.g. office and manufacturing space).</u>

First Construction

System Design

Difficulty: difficult

Restrictions (building type, materials, layouts, etc):

Design cost concerns: extensive costs to develop modular system for first time, as well as to design connections to utilities

System Construction

Skills and training procurement: none

Ease of construction: easy

Construction duration: no impact

Procurement concerns: yes

Safety concerns: no

Process changes:

Financial cost: $40.00/sf for materials (partitions, elec. terminals, ceiling, apertures). Labor is approximately $7.00/sf. Pods cover up to ~75% of plan area.

Conventional finish = $19.60/installed.

Net cost = (75% x $47) + (25% x $19.60) = $40.15/sf (pod area)

Operations and Maintenance

Financial cost: Not significant

Accessibility for operations and maintenance: worsened access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: material is nearly 100% reusable, only cost is labor to disassemble and reassemble.

	Office Pods	*Conventional*	*Savings*
Demolition	$7/sf	$1/sf	($6/sf)
Reconstruction	$7/sf	$19.60/sf	$12.60/sf
Total	$14/sf	$20.60/sf	$6.60/sf

Downtime: shortened – two weeks for complete disassembly and reconstruction

Tasks:

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld						X	X	X	X	X	X	X		X							
	Vm																					
Flow	Env						X	X	X	X	X	X	X		X				X	X	X	
	P/T						X	X	X	X	X	X	X		X				X	X	X	

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																		X	X	X	X
	Md																		X	X	X	X
Capacity	Ld	X																				
	Vm																		X	X	X	X
Flow	Env																		X	X	X	X
	P/T	X																	X	X	X	X

Design strategy achievements for Office Pod System

Design Strategy: **MODULAR PANEL CLADDING SYSTEM**

Facilities using design strategy: Igus Factory, US Navy Operational Training Facility
Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM:	**Enclosure**
ACHIEVES FLEXIBILITY IN SYSTEM:	**Enclosure**

DESCRIPTION OF STRATEGY: Standardized, modular panels of identical size and shape compose the enclosure of a building and can be removed and replaced individually with window, door, or wall panels. Panels are mounted with clamps on struts attached to the structural frame. Each panel serves as both enclosure (containing proper insulation) and interior finish. This is especially good for projects undergoing phased development, since the panels can be removed and reused easily, with minimal cost.

First Construction

System Design

- Difficulty: difficult
- Restrictions (building type, materials, layouts, etc): structural metal frame works better than concrete, simplifying connections to the mounting struts
- Design cost concerns: none

System Construction

- Skills and training procurement: none
- Ease of construction: easy
- Construction duration: shortened
- Procurement concerns: yes
- Safety concerns: no
- Process changes: Pre-assembly activities, fix vertical carrier mullions to structure, position panel 1, nip in place, position adjacent panel 2, set joint width, tighten, zip seals together, remove protective film
- Financial cost: $7.00 per square foot of wall area, installed (assume 22,500-sf wall)

Operations and Maintenance

Financial cost: Not significant

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: $4.00/sf of wall for labor. Alternative is cost prohibitive for conventional construction techniques

Downtime: shortened

Tasks: Loosen clamps, remove panel, position panel, set joint width, tighten, zip seals together, remove protective film.

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up			X	X																	
	Nw			X	X																	
	Md			X	X																	
Capacity	Ld			X	X																	
	Vm		X	X	X																	
Flow	Env			X	X																	
	P/T			X	X																	

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Modular Panel Cladding

Design Strategy: ACCESSIBLE MODULAR WIRING

Facilities using design strategy: K. Wayne Smith Building

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM:	**Services**
ACHIEVES FLEXIBILITY IN SYSTEM:	**Services**

DESCRIPTION OF STRATEGY: Wiring is composed of units with male-female connectors for simplified, fast rewiring. The flexibility of the wiring is often dependent on the finish system used, due to the physical interaction of these systems. Rewiring is performed simply by unclipping the connection, plugging into a new one, and pulling the wire to the proper location, if necessary.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: shortened
  - Procurement concerns: yes
  - Safety concerns: no
  - Process changes:
  - Financial cost: Variable about zero

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: improved access (somewhat dependent on finish system)

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: low – rewiring does not require new material, and happens with less labor

Downtime: shortened

Tasks:

Accessibility for renovation: improved access (somewhat dependent on finish system)

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up									X	X	X	X	X								
	Nw																					
	Md																					
Capacity	Ld									X	X	X	X	X								
	Vm									X	X	X	X	X								
Flow	Env																					
	P/T									X	X	X	X	X								

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Accessible Modular Wiring

Design Strategy: POKE-THROUGH FLOORS

Facilities using design strategy: Metro-Dade Center

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services**

DESCRIPTION OF STRATEGY: Horizontal distribution of wiring for a given floor is distributed through the ceiling of the floor below. To make new connections, a hole is drilled through the deck, and the wire is fed through to the upper floor. The chief advantage of such a system is that it allows a wire to be reached to any location on the floor without interference from walls and furniture in the occupied space.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc): deck should be cast in place, not pre-cast, to accommodate holes and incisions
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: slight increase for distribution, since cable trays are needed to properly route wiring to locations under the slab

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: demolition and repair cost (including fire-rated poke-through fitting) is approximately $150.00/change.

Downtime: shortened, but disruption is great for floor above as well as floor below

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up		O																O			
	Nw		O								X	X	X	X					O			
	Md		O																O			
Capacity	Ld		O								X	X	X	X					O			
	Vm										X	X	X	X								
Flow	Env		O																O			
	P/T		O								X	X	X	X					O			

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Poke-through Floors

Design Strategy: **EXPOSED CEILINGS WITH OVERHEAD DISTRIBUTION**

Facilities using design strategy: MIT Building 16, 270 Albany St., Building 314, Stop & Shop

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM:	**Services**
ACHIEVES FLEXIBILITY IN SYSTEM:	**Services**

DESCRIPTION OF STRATEGY: By eliminating the ceiling and distributing the utilities overhead (using cable trays, for example), utility access can be achieved from almost any point with minimal physical interaction with the finish systems. Some effort is often taken to provide an aesthetically pleasing distribution layout. This is especially common in lab spaces.

First Construction

System Design

- Difficulty: simple
- Restrictions (building type, materials, layouts, etc):
- Design cost concerns: none

System Construction

- Skills and training procurement: none
- Ease of construction: easy
- Construction duration: no impact
- Procurement concerns: yes
- Safety concerns: no
- Process changes:
- Financial cost: save \$2.75/sf on painting ceiling rather than using a hung ceiling = \$343,000 for a 125,000-sf building

Cost of cable trays: estimated by Wiremold to be \$400 per 12' length of tray, installed. For a 125,000-sf building, assume 6,000-lf of tray => \$200,000 total.

Operations and Maintenance

Financial cost: increased

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: low cost due to easy access, savings of $9.00/lf over drywall because of reduced demolition costs

Downtime: shortened – no demolition required

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up									X	X	X	X	X						X	X	
	Nw									X	X	X	X	X						X	X	
	Md																					
Capacity	Ld									X	X	X	X	X								
	Vm									X	X	X	X	X						X	X	
Flow	Env									X	X	X	X	X						X	X	
	P/T									X	X	X	X	X						X	X	

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up							X		X				X		X						
	Nw							X						X		X						
	Md																					
Capacity	Ld							X		X				X		X						
	Vm									X	X	X	X	X								
Flow	Env							X		X	X	X	X	X		X						
	P/T							X		X	X	X	X	X		X						

Design strategy achievements for Exposed Ceiling & Overhead Dist

Design Strategy: **EXTRA FIBEROPTIC LINES**

Facilities using design strategy: MIT Building 16

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services**

DESCRIPTION OF STRATEGY: In this strategy, extra fiberoptic lines are wired throughout the building even though they do not yet have a specified use. For high-tech labs or computer facilities, these lines will almost certainly be needed. By simply providing the extra lines, connections are provided at a variety of new locations, and extra load capacity is available for future use.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: lengthened
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes: none
  - Financial cost: extra set of lines installed

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: not applicable

Irrevocability of commitment: none

Change Implementation

Financial cost: significant over having to install the lines later, because of high demolition costs and increased complexity

Downtime: shortened

Tasks:

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld											X	X									
	Vm																					
Flow	Env																					
	P/T											X	X									

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Extra Fiberoptic Lines

Design Strategy: **STREET LAYOUT CONFIGURATION**

Facilities using design strategy: MIT Building 16, Mashpee Jr/Sr H.S., Aberdeen Proving Ground

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: Main lines for utilities are run throughout the corridors of hallways, and distributed from there to the rooms. This only works in buildings which are "hard finished" (i.e. the layout of rooms and corridors are defined to a certain degree).

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: Variable about zero – this simply changes the extent of space improvements provided by a developer and a tenant.

Operations and Maintenance

Financial cost: Not significant

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Variable about zero

Downtime: no impact

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw		O																	X	X	X
	Md																					
Capacity	Ld						X	X	X	X	X	X	X	X	X	X						
	Vm																					
Flow	Env						X	X	X	X	X	X	X	X	X	X				X	X	X
	P/T						X	X	X	X	X	X	X	X	X	X				X	X	X

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Street Layout

Design Strategy: **<u>HIGH DENSITY OF ELECTRICAL OUTLETS</u>**

Facilities using design strategy: MIT Building 16

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services**

DESCRIPTION OF STRATEGY: <u>Throughout the laboratories and offices of Building 16 at MIT, outlets were located at strips along walls and lab benches, providing a density of approximately five duplex outlets per 100-sf, over approximately 50% of the plan area. A typical outlet density would be two duplex outlets for the same area.</u>

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: lengthened
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: ($17 per outlet, installed) x (3 outlets per 100-sf) x (623 100-sf areas—assumed to be over half of building)
    = $32,000 increase for the base building cost

Operations and Maintenance

Financial cost: Not significant

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: none

Change Implementation

Financial cost: savings of $9.00/lf of change over conventional designs, due to demolition costs associated with rewiring

Downtime: shortened

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up									X												
	Nw									X												
	Md																					
Capacity	Ld									X	X											
	Vm																					
Flow	Env									X	X											
	P/T									X	X											

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for
High Density of Elec. Outlets

Design Strategy: SMALL AREA VARIABLE AIR VOLUME (VAV) UNITS

Facilities using design strategy: Abbott Laboratories, MIT Stata Complex

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: VAV units are used to control the thermal loads (heating and cooling) from HVAC units in a localized area. Providing many VAV units allows the space to be segregated into small areas, each with its own local control. At Abbott, where the usage of a large area is shared by office and manufacturing space, the proportions of which are constantly changing, the small areas allow office space to maintain a different climate or handle different loads, immediately adjacent to the manufacturing space.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: lengthened
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: slight increase – more units are more expensive to purchase and install

Operations and Maintenance

Financial cost: increased – some additional O&M are required to properly maintain the extra VAV units

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: no cost – simply adjust the control of the VAV unit. Alternative (major reconstruction of HVAC distribution system) is cost prohibitive.

Downtime: no impact

Tasks: adjust flow of air

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X													
	Nw																					
	Md																					
Capacity	Ld						X	X	X													
	Vm																			X	X	
Flow	Env						X	X	X											X	X	
	P/T						X	X	X											X	X	

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Small-area VAV Units

Design Strategy: **ACCESS FLOOR DELIVERY SYSTEM**

Facilities using design strategy: Owens Corning HQ, MIT Stata Complex

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services** **Finish**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: Steel or concrete panels are supported some distance off the floor (typically 6"-1'6" for offices) on pedestals, providing space in which wiring systems can be distributed and accessed easily. This space also serves as a pressurized plenum, through which cooled air is distributed. Air is vented to the occupied space through variable-volume vents in selected panels. Floor panels are typically 24" square in plan and 2" deep, and are fastened to the pedestals with machine screws. Of major concern, however, is that doorways, elevators, and areas where there are no raised floors align in height with the raised floor areas.

First Construction

- System Design
  - Difficulty: difficult
  - Restrictions (building type, materials, layouts, etc): doors, elevators, and floor areas adjacent to the raised floor area must align with the height of the raised floor.
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: difficult
  - Construction duration: no impact
  - Procurement concerns: yes
  - Safety concerns: no
  - Process changes:
  - Financial cost: Up to 100% reduction in horizontal ductwork is possible. Cost estimate of $18.00/sf is comparable to conventional designs, estimated at $18.29/sf — no increase

Operations and Maintenance

Financial cost: decreased - O&M on plenum are much easier than ducts, because of accessibility. Plenum must be kept clean, however, which may be harder to control because of the direct physical interactions with building users

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: Virtually no cost to move vents by moving a selected panel. Cost to change environmental flows is otherwise very expensive, and rarely undertaken. Savings are quite substantial, and the alternative (reconstruction of the HVAC distribution system) is assumed to be cost prohibitive.

Downtime: shortened

Tasks: Remove panel, (if replacement panel does not exist, measure, mark, and cut panel, then fit unit and attach), attach power to replacement panel, replace

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X													
	Nw						O	O	O													
	Md																					
Capacity	Ld						X	X	X													
	Vm																					
Flow	Env						X	X	X		X	X	X	X						X	X	X
	P/T						X	X	X		X	X	X	X						X	X	X

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X		X	X	X	X					X			
	Nw										X	X	X	X					X	X	X	
	Md										X	X	X	X					X			
Capacity	Ld										X	X	X	X								
	Vm																			X	X	
Flow	Env										X	X	X	X					X	X	X	X
	P/T										X	X	X	X					X	X	X	X

Design strategy achievements for Access Floor Delivery System

Design Strategy: **TASK LIGHTING SYSTEM**

Facilities using design strategy: Owens Corning HQ, MIT Stata Complex

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM:		**Services**	
ACHIEVES FLEXIBILITY IN SYSTEM:	**Enclosure**	**Services**	**Finish**

DESCRIPTION OF STRATEGY: Individual lights at desks and work areas supplement a low-power overhead lighting grid. This reduces overall power to the occupied space, reducing cooling loads, and allowing working areas to be established anywhere in the floor plan, without the concern of blocking light to other areas. In the event that windows are added or removed, the task lighting system can accommodate the changed lighting loads.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: small increase for the provision of task lighting units (i.e., lamps)

Operations and Maintenance

Financial cost: increased maintenance due to addition of task lighting units

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: no cost – plug-and-play. Alternative (reconstruct lighting system) is cost prohibitive.

Downtime: shortened

Tasks:

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up				X					X												
	Nw				X															X	X	
	Md																					
Capacity	Ld				X					X												
	Vm				X					X										X	X	
Flow	Env				X					X										X	X	
	P/T									X										X	X	

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Task Lighting

Design Strategy: ACCESS FLOOR HOUSING MECHANICAL DUCTS

Facilities using design strategy: Revenue Canada Building, The GAP at 901 Cherry St
Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services** **Finish**
ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: Steel or concrete panels are supported some distance off the floor (typically 6”-1’6” for offices) on pedestals, providing space in which wiring systems can be distributed and accessed easily. This space also serves as a pressurized plenum, through which cooled air is distributed. Air is vented to the occupied space through variable-volume vents in selected panels. Floor panels are typically 24” square in plan and 2” deep, and are fastened to the pedestals with machine screws. Contained in the plenum are air ducts that provide heat and cooling air to the building perimeter, which experiences different thermal loads than the rest of the building. These ducts must be constructed so that they do not obstruct airflow within the plenum to vital locations. Also, the depth of ducts is of some concern, since ducts are limited in their width, and deep ducts may raise the floor height substantially. Since they carry air to only a small area of the building, these ducts tend to be small. Of major concern, however, is that doorways, elevators, and areas where there are no raised floors align in height with the raised floor areas.

First Construction

System Design

Difficulty: difficult

Restrictions (building type, materials, layouts, etc): doors, elevators, and floor areas adjacent to the raised floor area must align with the height of the raised floor.

Design cost concerns: none

System Construction

Skills and training procurement: none

Ease of construction: difficult

Construction duration: lengthened

Procurement concerns: yes

Safety concerns: no

Process changes:

Financial cost: Assumed to be an 80% reduction in horizontal ductwork, which is 80% of total HVAC costs. Cost estimate of $18.00/sf for plenum delivery is comparable to conventional designs, estimated at $18.29/sf. Ductwork increases by $2.00/sf

Operations and Maintenance

Financial cost: decreased – O&M on plenum are much easier than overhead ducts, because of improved access. Plenum must be kept clean, which may be harder to control.

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: very inexpensive to move vents by moving a selected panel. Making changes at perimeter is more difficult, but fewer changes would be expected. Alternative is cost prohibitive.

Downtime: shortened

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X													
	Nw						O	O	O													
	Md																					
Capacity	Ld						X	X	X													
	Vm																					
Flow	Env						X	X	X											X	X	X
	P/T						X	X	X											X	X	X

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X		X	X	X	X					X			
	Nw										X	X	X	X					X	X	X	
	Md										X	X	X	X					X			
Capacity	Ld										X	X	X	X								
	Vm																			X	X	
Flow	Env																		X	X	X	X
	P/T										X	X	X	X					X	X	X	X

Design strategy achievements for
Access Floors with Mech. Ducts

Design Strategy: **ENHANCED PERFORMANCE CABLING SYSTEMS**

Facilities using design strategy: San Joaquin General Hospital

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services**

DESCRIPTION OF STRATEGY: These cabling systems are at the cutting edge of cabling technology, and are expected to become obsolete slower than traditional systems, because of their capacity to accommodate greater loads.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: no impact
  - Procurement concerns: yes
  - Safety concerns: no
  - Process changes: none
  - Financial cost: material cost increase

Operations and Maintenance

Financial cost: not applicable

Accessibility for operations and maintenance: no change

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: no cost – plug-and-play. Much less expensive than the cost to remove old wiring system and upgrade to the enhanced performance systems

Downtime: no impact

Tasks:

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw										X	X	X									
	Md																					
Capacity	Ld										X	X	X									
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

**Design strategy achievements for
Enhanced Performance Cabling**

Design Strategy: INTERSTITIAL SPACE BENEATH STRUCTURAL SLAB

Facilities using design strategy: Norwood Stop & Shop

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM: **Structure**

ACHIEVES FLEXIBILITY IN SYSTEM: **Structure** **Services**

DESCRIPTION OF STRATEGY: Rather than a slab on grade, a structural slab is used to create a small access area beneath the slab, where utilities can be distributed. The Stop & Shop uses these for areas where refrigeration units are to be placed, so that pipes can be easily accessed and rerouted when the unit is moved, rather than demolish and the slab.

First Construction

System Design

Difficulty: simple

Restrictions (building type, materials, layouts, etc): structural slab required (as opposed to slab on grade)

Design cost concerns: none

System Construction

Skills and training procurement: none

Ease of construction: easy

Construction duration: lengthened

Procurement concerns: no

Safety concerns: no

Process changes: excavate, construct foundation wall, pour slab on grade at bottom of excavation, finish, cure, forms for structural slab, pour slab

Financial cost: $35.00/sf for area (assume 1 bay = 625-ft) = $22,000

Operations and Maintenance

Financial cost: Not significant

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: savings of $37.00/sf x 625-sf = $23,000

	Slab on Grade	Structural Slab	Interstitial Space
Initial construction	$5.00/sf	$15.00/sf	$40.00/sf
Demolition	$2.00/sf	$7.00/sf	--
Reconstruction	$5.00/sf	$15.00/sf	--
Net cost	$12.00/sf	$37.00/sf	$40.00/sf
Time	30 days	90 days	1 day

Downtime: shortened

Tasks: remove pipe, core slab, route new pipe, connect to main, patch hole

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw	X																				
	Md	X																				
Capacity	Ld										X				X							
	Vm										X				X							
Flow	Env										X				X							
	P/T										X				X							

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Interstitial Space under Slab

Design Strategy: **<u>OVERHEAD DRAINAGE SYSTEM</u>**

Facilities using design strategy: Norwood Stop & Shop

Source of design strategy: EVAC, Inc.

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services** **Finish**

DESCRIPTION OF STRATEGY: The EVAC units are designed to allow drainage to run overhead under vacuum pressure, as opposed to underground using gravity power. Water collects in a small buffer until it reaches a certain level, triggering a vacuum, which removes the slug of water from the buffer, through a vertical pipe, into a drainage line at ceiling level, and finally into a drainage tank.

First Construction

- System Design
  - Difficulty: difficult
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: difficult
  - Construction duration: lengthened
  - Procurement concerns: yes
  - Safety concerns: no
  - Process changes:
  - Financial cost: $60,000 for entire system, installed

Operations and Maintenance

Financial cost: increased – some upkeep required for proper system maintenance

Accessibility for operations and maintenance: improved access

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: savings of $12.00/sf x 625-sf = $7500 per change

Downtime: shortened – significantly reduced from 30 days to 1 day

Tasks:

Accessibility for renovation: improved access – much better than traditional under-the-slab systems

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																		X			
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T													X								

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Overhead Drainage System

Design Strategy: EXTRA VACANT CONDUIT

Facilities using design strategy: Boston University Dorm

Source of design strategy: Summit Properties

DESIGN STRATEGY APPLIED TO SYSTEM: **Services**

ACHIEVES FLEXIBILITY IN SYSTEM: **Services**

DESCRIPTION OF STRATEGY: By providing a system of vacant ¾"-diameter conduit originating at a single location and terminating at each unit of a residential building, future services can easily be provided to each unit with minimal demolition of finish systems.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: lengthened
  - Procurement concerns: yes
  - Safety concerns: no
  - Process changes:
  - Financial cost: $0.25/sf

Operations and Maintenance

Financial cost: Not applicable

Accessibility for operations and maintenance: not applicable

Irrevocability of commitment: none

Change Implementation

Financial cost: savings of $12.00 per square foot for demolition, installation, and repair

Downtime: no impact

Tasks: locate terminus, pull wires

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw									X	X	X	X	X						O		
	Md																					
Capacity	Ld									X	X	X	X	X								
	Vm									X	X	X	X	X								
Flow	Env																			O		
	P/T																			O		

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for Extra Vacant Conduit

Design Strategy: **EXTRA FAST ACTING SPRINKLERS**

Facilities using design strategy: Toyota Parts Center

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM:	**Services**
ACHIEVES FLEXIBILITY IN SYSTEM:	**Services**

DESCRIPTION OF STRATEGY: These sprinklers trigger at 165-degF, as opposed to traditional sprinklers that trigger at 212-degF. This allows for the storage of plastic parts anywhere in this facility, which would otherwise be disallowed.

First Construction

- System Design
    - Difficulty: simple
    - Restrictions (building type, materials, layouts, etc):
    - Design cost concerns: none
- System Construction
    - Skills and training procurement: none
    - Ease of construction: easy
    - Construction duration: no impact
    - Procurement concerns: yes
    - Safety concerns: no
    - Process changes:
    - Financial cost: negligible cost for different sprinkler heads

Operations and Maintenance

Financial cost: Not significant

Accessibility for operations and maintenance: no change

Irrevocability of commitment: significant commitment

Change Implementation

Financial cost: cost to make changes in layout is now zero – parts can simply be moved in warehouse. Alternative is to remove and reinstall new heads at a cost of $890.00 each, with an assumed density of 6 heads per 1000-sf of area

Downtime: no impact

Tasks:

Accessibility for renovation: no change

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md															X						
Capacity	Ld																					
	Vm																					
Flow	Env															X				X		
	P/T															X				X		

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for
Extra-fast Acting Sprinklers

Design Strategy: **<u>HIGH DENSITY OF VERTICAL SHAFTS</u>**

Facilities using design strategy: 270 Albany St

Source of design strategy:

DESIGN STRATEGY APPLIED TO SYSTEM:	**Services**
ACHIEVES FLEXIBILITY IN SYSTEM:	**Services**

DESCRIPTION OF STRATEGY: By increasing the density of vertical shafts, the distance to utility connections is reduced for new equipment. This also reduces the distance for the horizontal distribution of ductwork, which reduces the depth of the ducts, and raises the allowable ceiling height.

First Construction

- System Design
  - Difficulty: simple
  - Restrictions (building type, materials, layouts, etc):
  - Design cost concerns: none
- System Construction
  - Skills and training procurement: none
  - Ease of construction: easy
  - Construction duration: lengthened
  - Procurement concerns: no
  - Safety concerns: no
  - Process changes:
  - Financial cost: Variable about zero

Operations and Maintenance

Financial cost: not significant

Accessibility for operations and maintenance: no change

Irrevocability of commitment: total commitment

Change Implementation

Financial cost: insignificant

Downtime: no impact

Tasks:

Accessibility for renovation: improved access

Attack Framework

		Structural System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

		Enclosure System																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Attack Framework

		Service Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up						X	X	X	X	X	X	X	X	X	X						
	Nw		O				X	X	X	X	X	X	X	X	X	X						
	Md		X				X	X	X	X	X	X	X	X	X	X						
Capacity	Ld						X	X	X	X	X	X	X	X	X	X						
	Vm																					
Flow	Env		O				X	X	X	X	X	X	X	X	X	X				X	X	
	P/T		O				X	X	X	X	X	X	X	X	X	X				X	X	

		Finish Systems																				
		Struct		Enclosure			Services												Finish			
		Sb	Sp	Wl	Ap	Rf	Ht	Vt	AC	Lit	Elc	Tel	Co	Sc	Pb	Fir	Cv	Sp	Flr	Wl	Ap	Clg
Function	Up																					
	Nw																					
	Md																					
Capacity	Ld																					
	Vm																					
Flow	Env																					
	P/T																					

Design strategy achievements for High Density of Vertical Shafts

APPENDIX C

Appended tables describing results of the analysis performed during this research, from Chapter 5 of this document

Project	Number of needs in term			Percent of needs in term			Most needs in term:	Building usage class
	Short	Medium	Long	Short	Medium	Long		
270 Albany Street	8	19	1	29%	68%	4%	Medium	R&D
Aberdeen Proving Ground	7	17	1	28%	68%	4%	Medium	R&D
9/90 Corporate Center	23	3	1	85%	11%	4%	Short	Office
Gap, Inc.	16	7	1	67%	29%	4%	Short	Office
K. Wayne Smith	16	7	1	67%	29%	4%	Short	Office
Metro-Dade Center	16	7	1	67%	29%	4%	Short	Office
Owens Corning	16	7	1	67%	29%	4%	Short	Office
Revenue Canada	16	7	1	67%	29%	4%	Short	Office
Building 314	8	17	1	31%	65%	4%	Medium	Office & R&D
Unilever Research	28	18	1	60%	38%	2%	Short	Office & R&D
Abbott Labs	29	7	1	78%	19%	3%	Short	Office & Manufacturing
Igus Factory	49	18	22	55%	20%	25%	Short	Office & Manufacturing
Boston University Dorm	5	13	4	23%	59%	18%	Medium	Residential
Summit Apartments	5	13	4	23%	59%	18%	Medium	Residential
Building 16, MIT	1	6	21	4%	21%	75%	Long	Educational
Mashpee Jr/Sr HS	3	4	6	23%	31%	46%	Long	Educational
Stata Complex, MIT	14	5	5	58%	21%	21%	Short	Educational
US Navy Anti-Sub Training Center	25	9	5	64%	23%	13%	Short	Educational
Mount Auburn Hopital	16	42	1	27%	71%	2%	Medium	Medical
San Joaquin General Hospital	16	44	1	26%	72%	2%	Medium	Medical
Stop & Shop Norwood	5	8	1	36%	57%	7%	Medium	Retail
Toyota Parts Facility	1	6	0	14%	86%	0%	Medium	Warehouse

Table C.1 – Number of expected changes that owners need to accommodate, distribution of the users' needs expected in each term, and building usage class

	S=Structure, E=Enclosure, V=Services, F=Finish															
Strategy applied to:	S	S	S	S	E	E	E	E	V	V	V	V	F	F	F	F
Strategy achieves flexibility in:	S	E	V	F	S	E	V	F	S	E	V	F	S	E	V	F
Design Strategies																
False slab			x													
Exterior wall concrete knockout panels		x				x										
Interstitial mezzanine floor rack system	x															
Z-layout configuration	x		x								x	x				
Structural "ladder" assembly system	x															
Centralized configuration	x		x						x		x					
Single/multi-channel surface raceways											x	x			x	x
Overhead cable trays											x	x				
Structural column overcapacity	x		x													
Oversized vertical distribution shafts			x													
Two-end core layout	x		x	x					x		x	x				
Raised flooring															x	x
Demountable mid-height partitions																x
Demountable full-height partition walls																x
Monoblock partition systems															x	x
Site-fixed panel partition systems															x	x
Utility risers at columns											x	x				
Room size standardization															x	x
Column-free zones in structure	x			x												
Office pod system											x	x	x		x	x
Modular panel cladding system					x	x										
Accessible modular wiring											x					
Poke-through floors											x					
Exposed ceilings with overhead distribution											x	x			x	
Extra fiberoptic lines											x					
Street layout											x	x				
High density of electrical outlets											x					
Small-area VAV units											x	x				
Access floor delivery system											x	x			x	x
Task lighting system										x	x	x				
Access floors housing mechanical ducts											x	x			x	x
Enhanced performance Category 5 cabling											x					
Interstitial space beneath structural slab	x		x													
Overhead drainage system											x	x				
Extra vacant conduit											x					
Extra-fast acting sprinklers											x	x				
High density of vertical shafts									x		x	x				

Table C.2 – Systems to which design strategies are applied and in which they achieve flexibility. An "x" indicates that a strategy is applied to a particular building system, and results in improved flexibility in a particular system, which may or may not be the same.

	Strategy Applied to System...:				
...and to System:	**Structure**	**Enclosure**	**Services**	**Finish**	**Any**
Structure	False slab Interstitial mezzanine Structural ladder Structural overcapacity Oversized shafts Column-free zones Interstitial space	Exterior wall concrete knockout panels	Z-layout configuration Centralized configuration Two-end core layout		11
Enclosure		Modular panel cladding system			1
Services			Overhead cable trays Utility risers at columns Accessible modular wiring Poke-through floors Extra fiberoptic lines Street layout High density of electrical outlets Small-area VAV units Task lighting system Enhanced performance cabling Overhead drainage system Extra vacant conduit Fast-acting sprinklers High density of vertical shafts	Multi-channel surface raceways Office pods Exposed ceilings with overhead distribution Access floor delivery system Access floors with mechanical ducts	19
Finish				Raised flooring Mid-height partitions Full height partitions Monoblock partitons Site-fixed panel partitions Room size standardization	6

Total
37

Table C.3 - Design strategies and the systems to which they are applied. Strategies applied to only one system are along the diagonal of the matrix. Multi-system strategies are off the diagonal.

Phase of building life					Initial Construction							Operations and maintenance phase			Change implementation				
Cost or benefit					Design difficulty	Ease of construction	Construction duration	Safety concerns	Procurement concerns	Financial cost		Financial cost	Accessibility for O&M	Irrevocability of commitment	Financial cost	Downtime	Accessibility for renovation	Benefit to cost ratio	BCR range
Measurements	System applied				simple	easy	no impact	no	no	$ per sf increase	bldg % increase	increased	no change	none	sf increase	no impact	no change	Value	
					difficult	difficult	shortened	yes	yes	*Variable about zero*	*Variable about zero*	not significant	improved access	significant	*Alternative is cost prohibitive*	shortened	improved access	*Alternative is cost prohibitive*	
							lengthened					decreased	worsened access	total	*Variable about zero*	lengthened	worsened access	*Variable about zero*	
												not applicable	not applicable					*Zero cost*	
Design strategy	Structure	Enclosure	Services	Finish															
False slab	S				simple	easy	lengthened	no	no	$0.72	0.79%	not applicable	improved access	total commitment	($4.23)	shortened	improved access	5.84	5-10
Exterior wall concrete knockout panels	S	E			simple	easy	no impact	no	no	$0.00	0.00%	not applicable	not applicable	none	Alternative is cost prohibitive	shortened	improved access	Alternative is cost prohibitive	ACP
Interstitial mezzanine floor rack system	S				simple	difficult	shortened	no	yes	$0.00	0.00%	not applicable	no change	none	Alternative is cost prohibitive	shortened	improved access	Alternative is cost prohibitive	ACP
Z-layout configuration	S		V		simple	easy	no impact	no	no	Variable about zero	Variable about zero	not significant	no change	total commitment	Variable about zero	no impact	improved access	Variable about zero	VAZ
Structural "ladder" assembly system	S				simple	easy	no impact	no	no	$0.16	0.17%	not applicable	not applicable	total commitment	Alternative is cost prohibitive	shortened	no change	Alternative is cost prohibitive	ACP
Centralized configuration	S		V		simple	easy	no impact	no	no	Variable about zero	Variable about zero	not significant	no change	total commitment	Variable about zero	no impact	improved access	Variable about zero	VAZ
Single/multi-channel surface raceways			V	F	simple	easy	no impact	no	yes	$0.78	0.85%	not significant	improved access	significant commitment	($2.25)	shortened	improved access	2.88	2-5
Overhead cable trays			V		simple	easy	no impact	no	yes	$1.61	1.75%	not significant	improved access	significant commitment	($2.25)	shortened	improved access	1.40	1-2
Structural column overcapacity	S				simple	easy	no impact	no	no	$0.00	0.00%	not applicable	not applicable	total commitment	Alternative is cost prohibitive	shortened	no change	Alternative is cost prohibitive	ACP
Oversized vertical distribution shafts	S				simple	easy	no impact	no	no	Variable about zero	Variable about zero	decreased	improved access	significant commitment	$0.00	shortened	improved access	Variable about zero	VAZ
Two-end core layout	S		V		simple	easy	no impact	no	no	Variable about zero	Variable about zero	not significant	no change	total commitment	Variable about zero	no impact	improved access	Variable about zero	VAZ
Raised flooring				F	simple	difficult	lengthened	no	yes	$1.87	2.04%	decreased	improved access	significant commitment	($2.25)	shortened	improved access	1.20	1-2
Demountable mid-height partitions				F	simple	difficult	no impact	no	yes	$4.00	4.36%	not significant	no change	significant commitment	($2.25)	shortened	no change	0.6	<1
Demountable full-height partition walls				F	simple	difficult	no impact	no	yes	$1.50	1.63%	not significant	no change	significant commitment	($2.25)	shortened	no change	1.50	1-2
Monoblock partition systems				F	simple	difficult	no impact	no	yes	$4.00	4.36%	not significant	no change	significant commitment	($2.25)	shortened	no change	0.6	<1
Site-fixed panel partition systems				F	simple	difficult	no impact	no	yes	$0.00	0.00%	decreased	improved access	significant commitment	($2.25)	shortened	improved access	Zero Cost	Zero Cost
Utility risers at columns			V		difficult	easy	lengthened	no	no	Variable about zero	Variable about zero	not significant	no change	significant commitment	($0.42)	shortened	improved access	Variable about zero	VAZ
Room size standardization				F	simple	easy	no impact	no	no	Variable about zero	Variable about zero	not applicable	no change	total commitment	Variable about zero	no impact	no change	Variable about zero	VAZ
Column-free zones in structure	S				difficult	difficult	no impact	no	no	$9.84	10.72%	not applicable	improved access	total commitment	Variable about zero	no impact	improved access	Variable about zero	VAZ
Office pod system			V	F	difficult	easy	no impact	no	yes	$20.55	22.38%	not significant	worsened access	significant commitment	($4.95)	shortened	no change	0.2	<1
Modular panel cladding system		E			difficult	easy	shortened	no	yes	$0.00	0.00%	not significant	improved access	total commitment	Alternative is cost prohibitive	shortened	improved access	Alternative is cost prohibitive	ACP
Accessible modular wiring			V		simple	easy	shortened	no	yes	Variable about zero	Variable about zero	not significant	improved access	significant commitment	($0.31)	shortened	improved access	Variable about zero	VAZ
Poke-through floors			V		simple	easy	no impact	no	no	$1.61	1.75%	not significant	improved access	significant commitment	$0.23	shortened	improved access	0.0	<1
Exposed ceilings with overhead distribution			V	F	simple	easy	no impact	no	yes	$0.16	0.17%	increased	improved access	significant commitment	($2.25)	shortened	improved access	14.1	10-20
Extra fiberoptic lines			V		simple	easy	lengthened	no	no	$1.00	1.09%	not significant	not applicable	none	($13.00)	shortened	no change	13.0	10-20
Street layout			V		simple	easy	no impact	no	no	Variable about zero	Variable about zero	not significant	improved access	total commitment	Variable about zero	no impact	improved access	Variable about zero	VAZ
High density of electrical outlets			V		simple	easy	lengthened	no	no	$0.26	0.28%	not significant	improved access	none	($2.25)	shortened	improved access	8.82	5-10
Small-area VAV units			V		simple	easy	lengthened	no	no	$1.25	1.36%	increased	no change	significant commitment	Alternative is cost prohibitive	no impact	no change	Alternative is cost prohibitive	ACP
Access floor delivery system			V	F	difficult	difficult	no impact	no	yes	$0.30	0.33%	decreased	improved access	total commitment	Alternative is cost prohibitive	shortened	improved access	Alternative is cost prohibitive	ACP
Task lighting system			V		simple	easy	no impact	no	no	$0.50	0.55%	increased	no change	significant commitment	Alternative is cost prohibitive	shortened	no change	Alternative is cost prohibitive	ACP
Access floors housing mechanical ducts			V	F	difficult	difficult	lengthened	no	yes	$2.30	2.50%	decreased	improved access	total commitment	Alternative is cost prohibitive	shortened	improved access	Alternative is cost prohibitive	ACP
Enhanced performance cabling system			V		simple	easy	no impact	no	yes	$0.66	0.71%	not applicable	no change	significant commitment	($9.02)	no impact	no change	13.6	10-20
Interstitial space beneath structural slab	S				simple	easy	lengthened	no	no	$0.18	0.19%	not significant	improved access	total commitment	($0.06)	shortened	improved access	0.3	<1
Overhead drainage system			V		difficult	difficult	lengthened	no	yes	$0.48	0.52%	increased	improved access	significant commitment	($300.00)	shortened	improved access	622.5	>20
Extra vacant conduit			V		simple	easy	lengthened	no	no	$0.25	0.27%	not applicable	not applicable	none	($12.00)	no impact	no change	48.0	>20
Extra-fast acting sprinklers			V		simple	easy	no impact	no	yes	$0.00	0.00%	not significant	no change	significant commitment	($5.36)	no impact	no change	Zero Cost	Zero Cost
High density of vertical shafts			V		simple	easy	lengthened	no	no	Variable about zero	Variable about zero	not significant	improved access	total commitment	$0.00	no impact	no change	Variable about zero	VAZ

Table C.4 - All strategies and measures for evaluating the value of each strategy’s flexibility

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